Circular No. 837

Streambank Erosion Control on the Winooski River, Vermont

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UNITED STATES DEPARTMENT OF AGRICULTURE
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This circular gives the case history of streambank erosion control and flood-plain protection on the Winooski River, Vermont. Like scores of other streams in the Northeast, the Winooski has cut away its banks. It has overrun its channel. It has taken short cuts or long meanders across farm fields. It has staged destructive floods. The following pages give an account of the measures used by landowners with the cooperation of the Soil Conservation Service to curb the destructive erosion of this stream. These included vegetative and mechanical measures, separately and in combination. Both successful and unsuccessful efforts are described. Finally, those measures and structures that proved most successful in checking erosion and flood damage are briefly summarized in order that this information may be of service to thousands whose homes and farms are on other streams of New England and the Northeast.

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Streambank Erosion Control on the Winooski River, Vermont [1]

By Frank C. Edminster, *Regional Biologist*, Walter S. Atkinson, *Regional Engineer*, and Arthur C. McIntyre, *Regional Forester, Northeastern Region, Soil Conservation Service*

CONTENTS

[1] Most of the work on the Winooski project by the Soil Conservation Service was done under the supervision of Reuben R. Zile, formerly project forester and later project manager; Brandon Wright, formerly project manager; Edwin R. Kinnear, formerly project engineer; F. Edward Crosby, formerly engineering assistant and later project engineer; L. Stanford Altpeter, formerly project forester; and Kenneth P. Wilson, formerly engineering assistant. Louis M. Glymph, Jr., and George S. Rupp, formerly zone conservationists, assisted with interim evaluations and progress reports. Information on flood data, Appendix, p. 50, was prepared by L. C. Gottschalk of the Washington research staff.

INTRODUCTION

The Winooski River drains a considerable part of Washington and Chittenden Counties in northern Vermont, flows generally westward, and enters Lake Champlain a few miles north of the city of Burlington (see map, pages 28 and 29). The farm lands most affected by floods and erosion are along its lower channel from Jonesville to the mouth. The streambank-erosion-control work discussed here was done in that area.

The lower section of the Winooski meanders through a 5,000-acre flood plain, almost all of which is valuable farm land frequently inundated by floods. At various times in the past, the river has cut several new channels, and there is evidence of comparatively recent channel shifts. Few places in the valley have escaped this channel cutting and much valuable land has been damaged or ruined. Some fields have been cut in two, leaving "islands" inconveniently situated for farming operations. Others have been covered with a layer of gravel that makes the fields unfit for farming for a long time.

Even when the stream stays in its channel, bank-full high water undercuts the banks along straight stretches of the river and on the outside curve of bends. Heavy grazing denudes the banks of protective vegetation, and plowing the land next to the edge of the bank loosens the soil. This speeds up bank cutting by high water. As banks are undercut, large trees on the edge topple over and cause damage by diverting currents and forming holes in the bank.

Until 1927, riverbank erosion apparently caused little trouble. Riverbank farmers kept erosion in check by simple bank control measures. A devastating flood in the autumn of 1927, however, caused such over-whelming damage that home-made repairs were no longer adequate. Few were attempted. It was locally recognized that outside assistance was needed. Another severe flood in the spring of 1936 increased damages and stream channel hazards.

At the request of local people and the University of Vermont, a survey was conducted by the Soil Conservation Service to determine the feasibility of establishing a soil-erosion-control demonstration project in the area. Dean J. E. Carrigan of the University of Vermont gave local leadership in the initiation of an operational program. The survey revealed that erosion control was a two-fold problem involving the treatment of the watershed as well as the riverbanks. While the program laid particular stress on streambank-control measures, the broad plan of operations approved for the project provided for giving full consideration to the soil conservation needs of the entire watershed and for treating all lands, as needed, in accordance with complete farm conservation plans. Plans were to be developed with interested landowners, on a voluntary basis, for the treatment of croplands, pastures, woodland, and the streambanks along the river farms.

Field work began with establishment of the project office in Burlington on October 1, 1936, and the first cooperative farm-conservation plan was completed shortly thereafter. Technicians with training in engineering, agronomy, and forestry developed plans and supervised installation. The only funds available for riverbank-control work were those appropriated for the Soil Conservation Service. Since these were limited and there was no prospect of obtaining local, State, or Federal funds for maintenance of structures after completion, all measures had to be simple in design, easy to construct, and of such a nature that the farmers could maintain them with material available on the farm.

Under these limitations, standard types of permanent structures could not be built. Dependency was placed mainly on vegetative control supplemented by temporary and semipermanent log and stone structures. The structures were designed primarily to protect the banks until vegetative control could be established. Stone riprap, however, was used to protect permanently the base of slopes.

Although temporary structures had been used successfully in the Western States, the Service had no experience with such structures on rivers having the physical characteristics of the Winooski. In this area, therefore, these structures were largely of an experimental nature. Many types were used in order that their suitability and value in flood and erosion control could be determined. There were 340 farms in the project area of 71,000 acres. Complete conservation plans were made for 189 farms with an area of 36,770 acres. The project was formally closed on June 1, 1940. At that time conservation practices had been established on 24,416 acres and practically all of the planned riverbank work had been installed.

Some of the structures along the river were maintained in good condition during the 4-year life of the project. Others were maintained for only a short time or were poorly kept up. Owing to lack of adequate maintenance generally, it was impossible to make a complete test of the relative worth of measures under long-continued use. The effectiveness of various measures is clearly evident, however, from the results obtained. A study of these results, together with information on measures used elsewhere under comparable conditions, indicates that a number of measures for erosion and flood control are generally applicable on the Winooski and in the surrounding region. These are described briefly in the following pages.

CONDITIONS ON THE WINOOSKI RIVER WATERSHED

The Winooski River is typical of the large streams of New England. It has a drainage area of 1,076 square miles or 698,640 acres, which is about one-tenth the area of the State. The watershed lies within an area of fairly evenly distributed annual rainfall of 36 inches. The average runoff is 19.4 inches per year or 54 percent of the precipitation. Seven tributaries in the headwaters have runoff of 65 to 75 percent of the rainfall.

The amount of runoff at any given time depends largely upon the conditions of the soil and cover. In general, there is almost no runoff in dry seasons or when temperatures are below freezing. The spring runoff may be as high as 400 percent of the rainfall during this period due to the melting of accumulated snow. Although much of the area is wooded, the soils are very thin, forming a mere shell over the parent rock. Soil storage capacity, therefore, is low. When ice forms on the ground surface prior to heavy snowfall infiltration may be negligible. Furthermore, deep percolation is definitely reduced by the relatively impermeable bedrock.

Prevailing width of the flood plain is between 1,000 and 3,000 feet. In the gorges, however, the plain narrows to much less than 1,000 feet. At the mouth of the river it widens to 2½ miles. Some of the best cultivated lands in the State are located along the 90-mile length of the Winooski flood plain. The land in the remainder of the watershed is steep, rough, and mountainous. The elevation varies from 100 feet at Lake Champlain to 4,400 feet at Mount Mansfield, some 25 miles distant.

The soils and topography have been developed on Ordovician limestone and Pleistocene glacial deposits.

Temperatures and precipitation are greatly influenced by the Green Mountains, Adirondack Mountains, and Lake Champlain. Summer and winter temperatures are more moderate in the lake valley than on the plateau and hill lands to the east. The average length of growing season in the valley is 160 days. It decreases with elevation and is as short as 100 days in the hilly sections.

THE PROJECT AREA

The project area, comprising about 71,100 acres, includes most of the Winooski watershed below Jonesville. The greatest east-west distance is 21 miles, the maximum north-south length 16 miles. In this area the river winds a distance of 33 miles and falls a total of 207 feet with an average fall of 6.4 feet per mile. The highest elevation is at Bolton Mountain on the eastern boundary.

The narrow river valley with its fertile, alluvial soils includes 1,554 acres of valuable farm land in the project area. Above the valley is a broad plateau of gently sloping to rolling farm land merging on the east with the foothills of the Green Mountains. This plateau, about 6 miles wide, is incised by many steep drainageways leading to the river.

Slopes in the project area are slightly to gently sloping on 25 percent of the land, moderately sloping on 51 percent, and steep on 24 percent. Agricultural use and lumbering have caused sheet erosion on most of the area. Only 10 percent of the area had no appreciable erosion, but 46 percent had been slightly eroded (up to 25 percent of topsoil gone) and 44 percent had been moderately or severely eroded (from 25 percent to 100 percent of topsoil gone). Two percent of the area had been damaged by severe sheet erosion or gullies, and 1.2 percent of the area was affected by wind erosion.

The predominant soil types are Pittsfield and Woodbridge loam, Hollis and Sheldon fine sandy loam, Suffield and Saco silt loam, Adams loamy fine sand, Hadley very fine sandy loam, and rough stony land.

Present Land Use—Farming and Lumbering

Land in farms at the time of the survey was 60,435 acres. The remaining 10,665 acres were in forest (not part of a farm), urban centers, and other miscellaneous uses. Some 800 acres of land, used as the source of water supply for Essex Junction, had been reforested.

Approximately 32 percent of the farming area was in cropland, 32 percent in open pasture, 25 percent in pastured woods, 9 percent in unpastured woods, and 2 percent in other uses.

Over 70 percent of the farms carried on dairying from which many farmers received 90 percent or more of their income. There were a few general farms and a few part-time units.

The usual custom on the dairy farms is to raise enough roughage to feed as many cattle as can be conveniently handled, and to purchase necessary concentrates. It is common practice to follow a 5- or 6-year rotation on the cropland. This consists of 1 or 2 years of silage corn, 1 year of oats or oats and barley, and 3 to 5 years of hay. Very little corn is grown for grain. Much of the small grain is cut for hay.

Maple sap and wood products are important in the economy of many farms, especially in hilly sections; yet good woodland management has rarely been practiced. Almost three-fourths of the woodland is grazed. The steepest slopes, because inaccessible, have not been severely grazed. In cutting, even for low-grade products, the best trees have been taken first. Conifers have been overcut, leaving stands composed mostly of hardwoods. Even the sugar-bush groves are being cut and few are being replaced.

Clear Cutting Speeds Erosion

Much of the lumbering is done by the farmer as winter work. This has provided fuel, fence posts, and repair lumber for farm use and for sale off the farm. The trees left after logging grew fast enough to replace the volume of wood taken out, but the remaining trees were poorer and the quality of the woodland declined. There has been an increasing tendency to sell tree stands "on the stump" to outside dealers. Under this system the farmer gets a lump sum of cash for the acreage sold, and the buyer harvests only the best and most marketable trees. The buyer brings in a portable sawmill, skins the area of all profit, then moves out. The farmer inherits a clear-cut area that will never again produce lumber for him.

This clear-cutting system of lumbering has damaging effects on the watershed. It results in greater runoff and soil loss. Less water is absorbed and stored in the soil. Snow, accumulated during the winter, melts more quickly in the spring. Consequently, floodcrests on the creeks, streams, and rivers become higher and more frequent, and the damage caused by floods in the valleys grows proportionately. The sponge of humus in the soil is quickly squeezed dry and no longer lets out its stored water slowly to feed the streams in dry periods. The streams alternately have too much or too little water.

Control of Streambanks in the Past

At first the banks of the Winooski eroded only slowly, and simple control measures taken by farmers were enough to prevent excessive damage. Farm labor was plentiful and a major activity each spring after floodwaters receded was to inspect the riverbanks for fresh damage, patch new breaks with stone, and remove lodged trees to prevent stream turbulence. The presence of submerged granite blocks at various places in the stream, originally placed on the banks, is evidence of previous efforts to keep soil losses in check. Bank erosion gradually increased, however, and the floods of 1927 and 1936 caused such devastation to farm land that farmers, with their limited resources, were unable to cope successfully with bank erosion.

More detailed information on the history of floods on the Winooski is given in the appendix.

PHYSICAL CHARACTERISTICS OF THE WINOOSKI RIVER

In the upper reaches of the Winooski River and in the tributaries which originate in the mountainous areas, stream gradients are very steep and stream velocities are high, up to 20 feet per second. The bed load during flood flows, consisting of gravel and large boulders with some sand, is very heavy. In contrast, that of the lower Winooski is mostly silt with little of the heavier material. The depth of the river above the backwater of the Essex Junction dam varies from 3 to 6 feet during normal stages. From there to the Winooski gorge the stream is deeper, with lower gradients and velocities and with sharp meandering bends.

Below the dam and falls at the town of Winooski the gradients are gentle and the water is generally deep, resulting in much lower velocities. There are numerous gravel bars on the inside of bends and wherever large eddies occur. The river has a stabilized gradient through the project area due to the controlling effect of the dams.

The total fall of the river from its source to Lake Champlain is about 1,300 feet, averaging 14 feet per mile. The fall in the upper portion of the river is 30 feet to the mile. In the lower portion the gradient is nearly flat, with deep water and low velocities.

The banks at normal water stage are from 10 to 30 feet high, averaging about 15 feet in height for most of the distance through the project. Actively eroding banks are vertical. The slope of naturally stabilized banks is approximately 1½:1 (1½ feet in a horizontal direction to each 1 foot vertical). The most severe erosion is on the outside curve of the bends where underwater scouring at the foot of the slope has weakened the bank. This apparently occurs during the falling stage of a bank-full flow after an over-bank flow has saturated the soil. Sections of farm land for distances up to 18 feet back from the shoulder of the bank have been lost in a single year.

Ice floes have contributed materially to bank erosion by destroying protective vegetation, gouging out the earth and creating turbulence in the stream. Large trees on the bank have also created turbulence, which has resulted in scouring. The trees eventually fell into the river and the tree tops, by throwing the current in a new direction, helped to increase the damage. In several cases, the river in shortening its course between bends has cut new channels through the bottom land. The severest test of control measures was that presented by the impact of high-velocity flood flows and heavy ice floes (fig. 1).

Stream-Channel Conditions Causing Erosion

The Winooski River transports considerable bed material such as sand, gravel and cobbles, particularly in its upper reaches, during

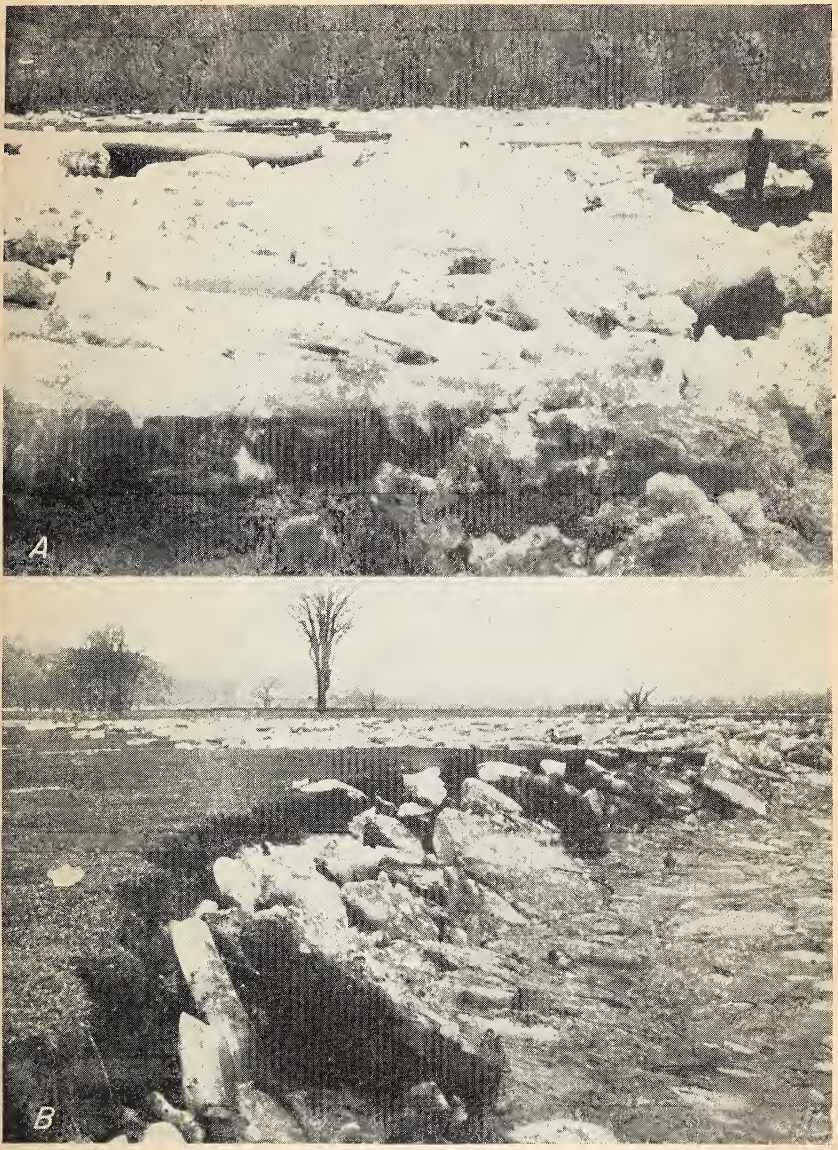

FIGURE 1.—Ice subjects all erosion-control measures to a severe test. *A*, Ice deposited on pasture by floodwater; *B*, erosion of bank caused by ice action.

flood stages. In its lower section the Winooski carries much less coarse material and more silt and clay.

There are two general classes of bank protection: (1) Those which retard flow along the bank and thereby promote deposition, and (2) those which, through some form of bank cover, protect the bank from direct erosion and scouring. Permeable jetties of log piling, rock, trees, or other materials are examples of protection causing deposition. Living vegetation, brush matting, riprap, concrete slabs, and asphalt lining are examples of protective bank cover. The type of protection needed for a specific case is largely determined by the characteristics of the stream.

Factors which must be considered in selecting measures for bank control include: The probable effect of logs, ice, and other floating material upon control devices; stability of bank material; channel width; curvature of stream; depth of water at the time control measures are installed; height of bank; and degree of protection required.

Removal of channel debris such as stumps and fallen trees, as a corrective measure, and annual channel maintenance to prevent such accumulations, are essential in streambank control. Properly designed protective devices will help keep the channel clear and reduce the hazard of damage to structures. However, structures alone cannot be expected to clear the channel of accumulations of debris.

Channel changes, including changes in stream alignment, involve a change in the stream's hydraulic characteristics in, above, and below the new channel. Merely straightening a channel, therefore, does not necessarily eliminate its tendency to meander. In many instances an erosion hazard is developed in the straightened channel and at both ends, since changes in velocity may cause the formation of bars downstream and shifts in current direction. New channels should be designed for capacities for a runoff expectancy consistent with the old channel above and below the new section. New channels should not be partly excavated with the expectation that floodwater will complete the excavation.

The type of protection needed for banks having straight alignment and for banks not subject to impinging or deflected currents of high velocity differs from the treatment for banks at curves and in reaches where currents are apt to strike the bank.

In straight channels the point of highest velocity is near the center of the channel and close to the top of flow. Protection in this case is usually provided by vegetation and a scour-resistant bank lining or revetment. When lining is used, the banks should be sloped sufficiently to be stable under the particular type of lining selected. For nonrigid lining, the slope must be gentle enough to prevent downward sliding of the lining. For the more rigid lining, the slope may be as steep as the retaining-wall properties of the lining will permit. Self-supporting revetments may be built of either pervious or impervious material, provided that the flow between revetment and bank is not permitted to reach a scouring velocity.

In curved channels the highest velocity is close to the outer edge of the channel and near the center of water depth. Erosion is caused by a rolling spiral (helicoidal) action in which the erosive force is mostly downward, causing undercutting and caving of the bank.[2] Because of this additional force, a more substantial and permanent type of construction is required for curving channels. The damage resulting from revetment failures is usually much greater at these vulnerable points than along unobstructed straight reaches of the channel. Deeper excavations should be made for foundations below the normal stream bed wherever there is any doubt of the stability of the foundation for the load it must take under submergence, and to provide against the more severe scour hazards.

Many tributaries of the main channel are high-velocity streams carrying heavy bed loads during flood flows. The change in velocity at the intersection with the main stream causes deposition of the bed load at or near this point, forming a bar. This bar forces the current of the main channel against the opposite bank, causing undercutting and erosion of the bank. In this case, it may be necessary to create desilting basins to reduce the amount of sand and debris carried by the tributary, or to install bed stabilization structures to lower the erosive velocity of the tributary.

MEASURES USED FOR BANK PROTECTION AND RESULTS

Protection From Domestic Livestock

There was abundant evidence to indicate that cattle and other farm animals had damaged the streambanks by trampling and heavy grazing. The animals, in climbing up and down the banks while seeking water and returning to pasture, loosened the soil. The natural plant cover on the banks—grasses, willows, alders, and other plants—was grazed or browsed in various degrees. Heavy grazing and trampling depleted the vegetation to the point where it was of little aid in holding the soil.

In order to establish a plant cover adequate for erosion control on these banks, therefore, it was first necessary to exclude farm livestock—a measure accepted by all the cooperating farmers. This was usually done by fencing off the bank portion of a pasture from the remainder of the field; or, in some cases, by adjusting the land use in such a way as to separate the pastures from the riverside fields. Although fencing cut off access to the stream as a source of water for livestock, this did not necessarily mean that the balance of the field had to be taken out of grazing use or that livestock production on the farm as a whole had to be curtailed. Most of the valley farms had other good water supplies that could be used instead of the river.

Since there were few farms pasturing sheep and hogs, three-strand barbed-wire fences were usually adequate. The fences were located far enough back from the shoulder of the bank to provide an ungrazed vegetated strip next to the river. Where stream currents were away from the bank or parallel to it, a rod width was allowed between top of bank and fence. Back of old chute heads, the width protected

[2] Knapp, F. H., and Libby, J. A., EROSION OF STREAMBANKS, ITS PREVENTION AND CORRECTION. Soil Conserv. Serv., Southwest Region, Regional Bul. 78. 1942.

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was 12 rods. For stream-current forces between these extremes, the protected width varied accordingly.

This practice, which was accepted by all cooperating farmers, proved to be fully effective so long as the fences were maintained. Where they were abandoned and animals were allowed to pasture the protected strip, the grass cover on the steep banks was soon damaged by trampling. The willows and red-osier dogwoods that had been planted were browsed back to stubs and most of them died. Removal of the plant cover left the upper part of the bank vulnerable to ice damage and severe erosion.

Vegetative and Mechanical Methods of Control

Sloping and Planting.—Most of the eroding banks were vertical and too steep for satisfactory treatment by planting or structural control without preliminary sloping. All steep banks were graded to a predetermined slope, the steepness of which depended mainly upon the kind of soil. A slope of 1½ : 1 was found suitable for the medium-textured soil common to this area, and this slope was used in most cases. The slope ratio was increased to 2 : 1 on the sandier soils and reduced to 1¼ : 1 on the heavier soils.

Treatment of a graded slope depends upon the probable severity of water and ice action on the bank. Sloping and revegetation suffice where stream currents are offshore and the bank is not undercutting.

Simple planting alone does not ordinarily develop an established cover fast enough to provide the necessary protection. Bank sloping and planting with native white willow (*Salix alba*), natural willow hybrids, and purple-osier willow (*Salix purpurea*) gave fairly good control without additional measures where the current was offshore; but in places where the thrust of the current was against the shore, the bank undercut.

Sloping, Planting, and Brush Matting.—Where more protection is needed than that afforded by sloping and planting, a mulch of hardwood brush fastened down with stakes and wire can be used, provided there is no danger of undercutting the bank. On sections of bank where the current paralleled the shore the results were about the same as with planting without the mulch. Except where the current was offshore, the bank undercut and fell in. Brush matting did not keep the stream from undercutting the planted bank.

Sloping, Riprapping at Toe of Slope, Brush Matting, and Planting.—This combination of protective measures was the most successful bank-erosion treatment used on the Winooski project. Riprapping was especially effective where the banks were subject to undercutting. It protects the toe of the bank below the water line (fig. 2). The only failures observed were where insufficient stone had been used or where the stone was not placed uniformly, resulting in irregular contours causing local turbulence and movement of the stone.

The riprap was hand-laid in some cases and loose-dumped in others. The materials used varied as to size, shape, and type of stone. The hand-laid stone was placed on a 1½ : 1 or 1¼ : 1 slope; the loose-dumped stone was allowed to remain where it fell. Banks were riprapped to a height of 2 to 5 feet above the normal water line, or the

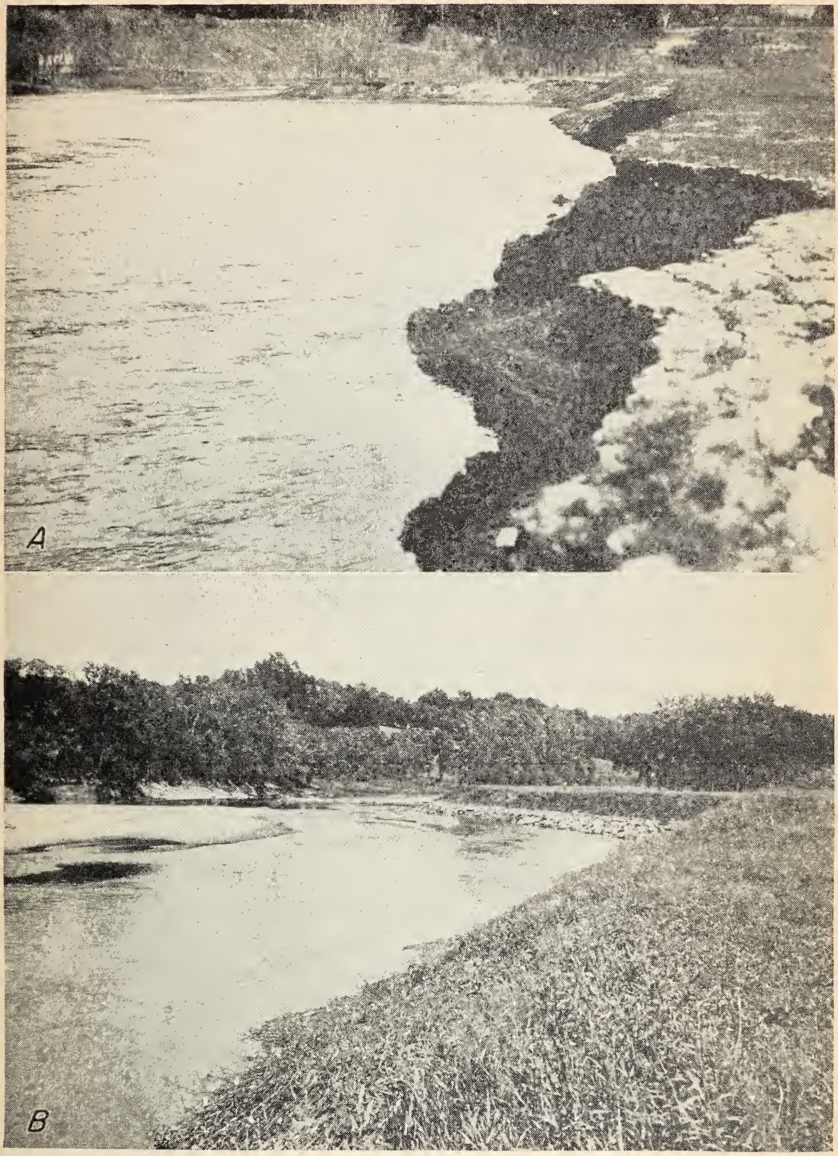

FIGURE 2.—A section of riverbank where erosion was successfully controlled by a combination of structural and vegetational measures. *A*, Bank erosion caused by 1936 flood, before treatment; *B*, same bank after sloping, with lower portion riprapped with stone, upper portion planted and brush-matted.

lower limit of thrifty plant growth. On sharp curves or where valuable property was endangered, riprap was usually carried to the top of the bank.

Angular stone gave good results, whereas rounded stone rolled too easily, regardless of size, and was not satisfactory. Small stone was not effective unless hand-laid on edge. Increased stability was obtained with size and quantity of rock used. Although quarried rock, up to several tons per stone, had been used with good success for railroad revetments at certain points along the river, most of the work on the demonstration project had to be done by hand labor and small trucks, and few stones over 100 pounds were used. Hard stones of irregular sizes and shapes, weighing from 10 to 100 pounds or more, were best. Quarried granites and other igneous rocks were better than stream-bed stone or sedimentary rocks.

Hardwood brush convenient to the site was used for mulch material on the bank above the riprap. This consisted mainly of willow and speckled alder (*Alnus incana*) with some elm, maple, and other hardwoods. Stems were cut with a thickness of about 1 inch or less and were laid to form a tight mat from 12 to 18 inches thick. Stakes about 3 feet long and about 3 inches in diameter were driven through the mulch at 3-foot centers, and No. 9 galvanized wire was laced around and between the stakes in a diamond-shaped pattern to hold down the mulch. It was found that staking and tieing down the mat, though expensive, was essential in order to keep the first high water from carrying the mulch away and to hold the soil of the exposed bank until the plants became established.

Of the different species of willow, only the tree type provided material large enough for stakes; but for bank control generally, the shrubby types were better than the tree willows.

In order to avoid exposing the bare soil any longer than necessary, the brush matting was applied immediately after the bank was sloped. It was found that hard, quick storms could cut an unmulched bank back several feet, even though the bank had been riprapped. Where this happened it was necessary to reslope the bank and riprap it again.

The need for applying the brush matting promptly after grading required careful planning of the time and order in which the bank sloping, riprapping, planting, and brush-matting operations were done. Both the seasonal requirements for planting and the mechanical difficulties of planting through the brush after the mat was placed had to be considered. Only raw, heavy cuttings can be used since seedlings, rooted cuttings, and small raw cuttings cannot be planted through the brush. Thus, while the brush-matting work was done from spring through fall, almost all planting was done in the spring. Many of the planting failures on the bank proper can be traced to attempts to plant raw cuttings. One must use a planting bar to open and close the holes, and usually the soil cannot be packed firmly against the cutting when working through the brush layer. Even a heavy, raw cutting cannot be planted properly through a brush mat if the soil is stony.

The best way to overcome these difficulties is to plant before mulching, regardless of season. The other alternative—doing the grading and riprapping work just before and during the spring and fall planting seasons—is not generally practicable, since summer is usually the best time for this preparatory work.

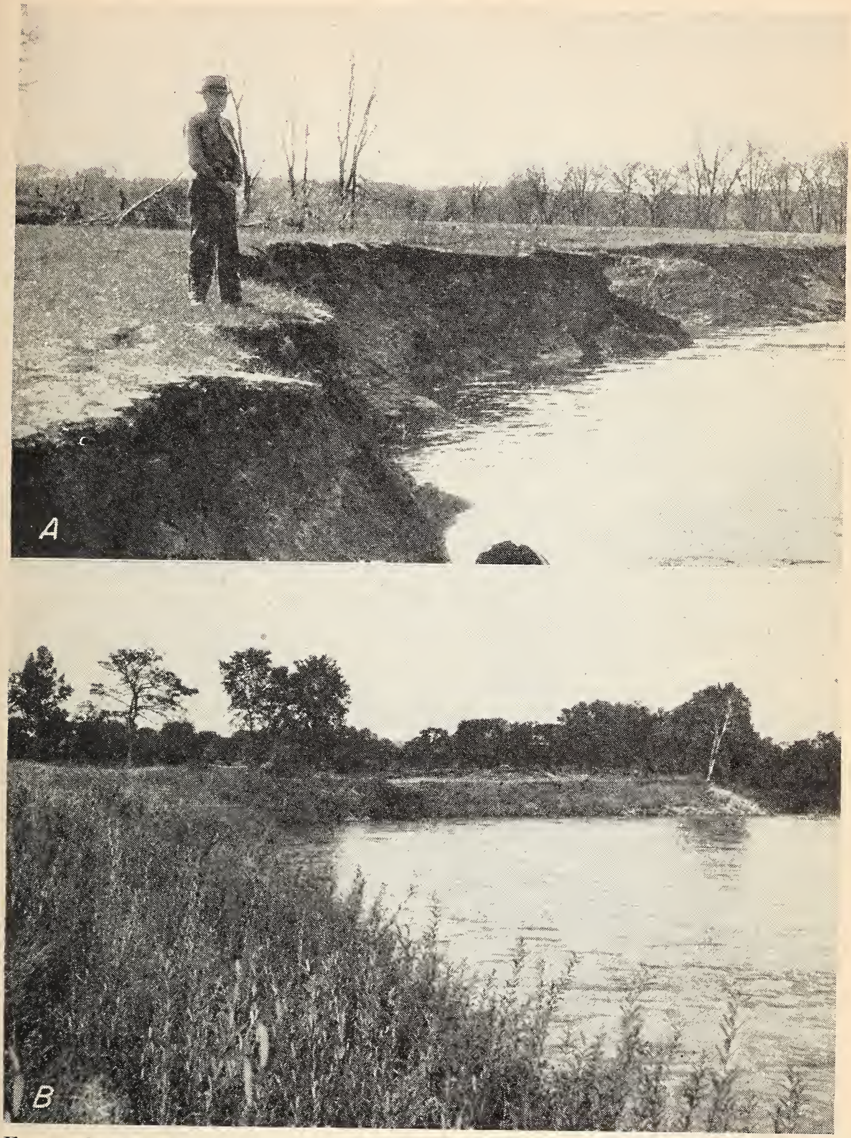

FIGURE 3.—Severely eroded riverbank. *A*, Prior to treatment in 1937; *B*, same bank in 1938 after it was sloped, brush-matted, and planted with purple-osier willows, and toe of slope riprapped. Willows are in second growing season. These photographs should be compared with the three following ones illustrating the conditions in later years.

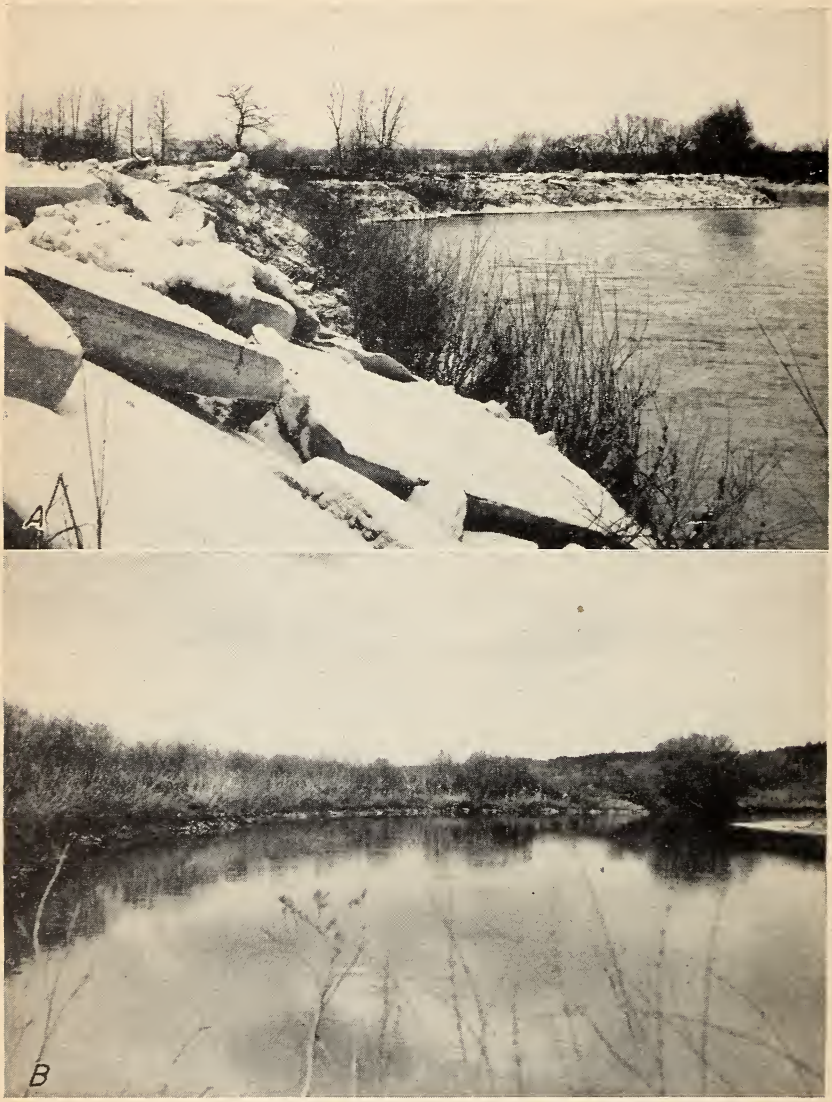

FIGURE 4.—Purple-osier willows are well adapted for bank-erosion control. *A*, Heavy layer of ice cakes deposited by spring flood on the bank shown in figure 3; *B*, same bank after ice receded. The resilient willows were scarred but remained intact and the bank is not seriously damaged.

The use of brush matting successfully prevented washing away of the soil by surface water. Generally, the brush was effective from 3 to 5 years. Where the plantings were a success, they took over the vegetative control before the mulch rotted out. Only where the water undercut the bank, due to lack of riprap or faults in its application, did the brush matting fail.

Species Used for Streambank Planting on the Winooski River

Most of the bank plantings were made of "native" willow, mainly white willow, with some hybrids of this and other willow species. Local material was used because it was handy and the only adequate supply at the time. Purple-osier willow, red-osier dogwood (*Cornus stolonifera*), and boxelder (*Acer negundo*) were used in considerable quantities. More purple-osier willow would have been planted had it been available. Poplars were planted on some sections of bank, on flat areas above the bank, and behind chute heads. The plants were various hybrids originally developed for use in pulpwood plantings.

Purple-Osier Willow.—Purple-osier willow was the outstanding plant for streambank control on the Winooski (figs. 3, 4, and 5). Nearly 89,000 cuttings and hundreds of poles were used, most of them on the streambank proper. Others were planted behind chute-head control structures, and some to provide a stock of cuttings for later use. Good to excellent survival was obtained in most cases.

The plants grew rapidly, especially in the first 4 or 5 years, generally reaching a height of 9 or 10 feet. The tallest planting was in a chute area protected by a barrier structure. It averaged 12 feet in

Figure 5.—By 1945, a well-vegetated bank had replaced the raw eroding bank shown in figure 3, *A*.

FIGURE 6.—Purple-osier willow is the best willow for streambank use in the Northeastern States. Its resilient stems assume their original erect form after having been flattened by ice and water. New plants grow from the silted-over tips.

height. Plants in moist soil reached a height of 15 feet, but on dry knolls growth was only about 6 feet. All plants in areas of standing water died. It was evident that bank plantings would never attain as great a height as those in well-drained chutes because of the variable moisture conditions on the banks and the severe damage inflicted upon the bank plantings by water and ice.

Purple-osier willow has a form of growth and produces a type of cover that makes it a better plant than others for bank control (fig. 6). It is of moderate height and the stems rarely exceed 1 inch in thickness. It is resilient enough to yield under the pressure of encroaching water and ice and to recover its erect form when the water goes down. It forms a skidway, instead of an obstruction, for ice cakes. Injury to plants due to scarring by ice and water is largely offset by the layering of stems and by fresh sprouting.

The results of the work on this project indicated that for planting of purple-osier willow to be effective in the control of bank erosion it is desirable to (1) brush mat the bank to help keep the planting from being washed out; (2) do the planting ahead of the brush matting; and (3) on banks subject to the impact of eroding currents, install and maintain some kind of mechanical protection for the toe of the bank in order to prevent undercutting. Banks that were not mulched soon washed out, resulting in a poor cover. Many more cuttings survived when the planting preceded the brush matting than when the cuttings were planted through a brush mat that had previously been installed. Banks with in-shore currents that had been planted and brush matted without adequate toe protection gave way through undermining.

There was some evidence to indicate that purple-osier willow poles were not as satisfactory as cuttings of this species for bank protection. The poles were more costly and more difficult to handle. Further trials with different sizes of cutting stock and poles are needed, however, to determine their relative suitability.

In summary, purple-osier willow gave excellent results when planted under favorable conditions. In unfavorable circumstances, this plant gave definitely better cover than any other species used.

Native and Hybrid Willows.—Raw cuttings and poles of the white or "native" willow and natural hybrids of this species with other willows present in the locality were used in greater volume than any other material. More than 545,000 cuttings and about 10,000 poles were planted. They were used extensively on both riverbank and chute areas. Considering the inherent nature of tree willows and the undesirability of trees on a riverbank, results were fairly satisfactory. Survival varied from excellent to poor. Growth was somewhat greater than with purple-osier willows. After 8 or 9 years, average height of the good native-willow stands was 15 feet with a maximum average growth of about 18 feet.

A good cover was produced on chute areas, but that on the banks varied from poor to good. On banks, the cover produced by poles was poorer than that from cuttings. The cover on the drier upper portion of banks was not so good as on the portions nearer the water.

Although the native-willow stands reproduced fairly well by sprouting, they suffered more permanent damage from water and ice than did those of purple-osier willow, because of the brittleness of their stems. As in the case of purple-osier willow, the difficulty of planting through brush mulch and the lack of adequate mechanical protection of the lower bank accounted for poor results.

Native willows of the tree-forming type were established successfully on banks and in chutes where site and planting conditions were favorable and where the slope was protected. It was evident, however, that the cover produced by tree willows would become too coarse for good bank control unless the growth was cut back periodically.

Poplar and Poplar Hybrids.—Poplar (*Populus*) and poplar hybrids were widely planted on riverbanks, on flat areas back from the banks, shoulders, and in old chutes. The planting stock included hybrids of numerous clones selected for suitability in streambank control. In some plantings, clones of known parent stock were segregated in plots for evaluation. No significant differences in success were observed among these varieties. About three-fourths of the hybrid cuttings were rooted stock. In addition to the hybrids, nearly 12,000 fresh cuttings of native poplar (mostly *P. tremuloides*) were used. The cuttings of native poplar, unlike those of hybrids, were free of infection by canker (*Dothichiza populea*), but this was of no great importance since all the poplars had objectionable characteristics which made them unsuitable for effective erosion control.

Survival of hybrid poplars planted on the streambank was generally poor. The trees which came through the first year later failed where brush matting was not applied or where tree deflectors placed along the bank for protection had washed out. In contrast, plantings in

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chutes and on field edges back of the bank were generally much better. Plants died, however, in chute areas that stayed wet too long. Average height growth varied from 10 feet on the banks to 16 feet on the flat areas. Trees were as low as 5 feet in height on banks that were not brush-matted, and as tall as 25 feet in one of the chutes.

It was evident that the poplars were unsatisfactory for erosion control, due primarily to disease. Even on sites where planting survival was high and the initial growth rapid, the plants soon became infected by canker. Only a few trees put out new sprouts.

Poplar is also subject to severe breakage by water and ice, because it is brittle and has little resiliency.

Boxelder (*Acer negundo*).—Both seedlings and seed spots of boxelder were used. There was evidence to indicate that the seed spots were not as effective as seedlings. On one farm, where seed spots were planted on the flat above the bank, survival was fair, but growth and cover were poor. On 14 farms, a total of 38,025 were planted, of which all but 7,500 were seedlings.

The survival of boxelder plantings generally was unsatisfactory. Of 5 bank plantings, 4 were poor and 1 was good. Of 10 chute and top-of-bank plantings, 1 had excellent survival and 3 each were good, fair, and poor, respectively. In the single case of good survival on the bank, the planting was severely damaged by ice.

Rate of growth was exceedingly variable. In 8 years the best average height was 18 feet and the poorest 1 foot. The average height of all plantings was 7 feet. In general, boxelder failed to provide a good erosion-control cover.

Since boxelder grows in tree form, it makes a poor plant for streambanks. Only by repeated cutting can it become an effective bank cover, even if well established. Although it is fairly flexible in its resistance to water and ice, it suffers great mechanical damage from which it does not recover well. Almost all results in both bank and flat-area sites were classed as failures.

Red-Osier Dogwood (*Cornus stolonifera*).—The only shrub species other than purple-osier willow that was planted on the riverbank was the red-osier dogwood. It was used only at the bottom of the bank at or just above the normal water level, the lowest part planted. Nearly 23,000 plants were used, all of which were seedlings.

Results were consistently good, the survival being 70 to 85 percent in all plantings. Growth for the 8-year period averaged 5 feet, with extremes of 4 feet and 7 feet. Regardless of height differences, all the plantings were probably mature for their sites.

Red-osier dogwood generally developed a good or excellent cover and produced new growth in abundance through layering of the branch tips. Plants grazed by cattle, however, were severely injured and in danger of being destroyed by browsing.

The natural characteristics of red-osier dogwood make it ideal for use on the lower part of the streambank. It is even more flexible than purple-osier willow, tends to prostrate itself at the edge of the water, and sustains mechanical damage well. Sprouting enables it to recover from breakage. The layering of the prostrate branches in the silt thickens the stand.

Speckled Alder (*Alnus incana*).—This native alder was included in much of the brush used for matting the banks. In some cases where the brush was applied in early autumn, stands were produced from the ripe seed carried on the branches. In one instance, alder largely displaced the planted poplar and native willow and became the dominant species on the streambank. It furnished an excellent cover about 8 feet high, adequately resilient for streambank-control purposes. The good cover produced by speckled alder on streambanks in several widely distributed areas indicates that alder mulch containing ripe seed may have a high value for brush matting. Its value as a bank cover needs further study.

Other Species Used.—None of the other species of trees, shrubs, and vines used in the flat area behind the streambank gave satisfactory results. Seedlings of silver maple (*Acer saccharinum*) had only fair to poor survival and grew to a height of only 6 to 9 feet in 9 years. The species developed only a fair or poor cover. It has no characteristics that make it especially useful on this kind of site.

Hackberry (*Celtis occidentalis*) generally had poor survival or failed completely. In 8 years, growth reached only 20 to 40 inches. It failed to produce a protective cover.

The plants produced on 2,700 seed spots of northern red oak (*Quercus borealis*) had uniformly poor survival and poor growth. None of the European mountain ash (*Sorbus aucuparia*) or Virginia creeper (*Parthenocissus quinquefolia*) survived. One of the two plantations of lilac (*Syringa vulgaris*) had no survival, the other had excellent survival but average growth in 8 years was only 22 inches. Black locust (*Robinia pseudoacacia*) survived poorly but growth of the trees that survived was fairly good, averaging 10 feet. The plants were badly infested with borers. Survival of red pine (*Pinus resinosa*) was poor, and no effective cover was developed. Growth in 8 years averaged 40 inches. Other plants found unsatisfactory for various reasons were sugar maple (*Acer saccharum*), eastern white pine (*Pinus strobus*), and arborvitae (*Thuja occidentalis*). Beachgrass (*Amophylla breviligulata*), planted on the bank of one farm, failed to survive.

Mechanical Structures Used for Streambank Control

Log Pile and Corrugated Sheet-Metal Revetment.—This measure was used on a section of riverbank about 1,200 feet in length. The bank is 18 feet high above normal water level. At the toe of the slope, the water is 8 feet deep. A vertical bank of blue clay extends below the normal water level. It is overlain by a layer of gravel, which in turn is overlain by a 14-foot layer of soil. Running springs seep through the gravel layer and cause continued slipping of the bank. The clay bank erodes and caves below the normal water level.

In order to avoid the high cost of building a retaining wall or stone riprap below the water line and laying tile drains along the bank, as a means of controlling the underwater caving of the bank, a less expensive method was tried. This consisted of driving timber piles on 4-foot centers along the toe of the slope, bracing the piles with timber spreaders, and facing them with sheets of galvanized iron treated with red lead paint and waterproofing material. Material obtained from bank sloping was used for backfill behind the metal sheets. The bank above the water line was brush-matted and planted (fig. 7).

FIGURE 7.—Revetment of log piling and corrugated metal. *A*, Retaining wall, with bank sloping, planting, and brush matting in various stages of completion, 1938; *B*, section of revetment destroyed by the impact of floods as photographed in 1945.

This type of structure was found to be unsatisfactory. The bank continued to slip, and the piles and metal deflector failed in several places owing to ice action and bank pressure.

To control bank erosion of this nature, it is necessary to cut off the underground seepage and stabilize the bank by the use of tile drains, or to build a retaining wall of sufficient strength to withstand bank pressure.

Whole-Tree Deflectors.—Control by whole-tree deflectors was used on several sections of the river where the normal water depth was about 14 feet and the stream current was slow. Trees with butt diameters of 2 or 3 feet were placed longitudinally along the river-bank with branches intact and with butts and tops slightly overlapping. The butts were fastened with heavy steel cable to stout wood piles driven 8 to 10 feet into the bank near the water line.

The purpose of these deflectors was to slow the current below the normal water line sufficiently to permit deposition of silt and thus prevent scouring at the toe of the slope. They were used in combination with vegetative blanket protection on the bank above the normal water line in the expectation that the portions of the trees below the water line would endure and effectively protect the toe of the bank for a long period of time (fig. 8).

The trees gave adequate protection for 4 or 5 years, but rotted and lost their effectiveness within 9 years. Although vegetative protection on the bank above them was better than average, large sections of bank slipped into the river as a result of undercutting below the water line at the toe of slope. Ice damage took a heavy toll of the trees.

Due to ice damage, lack of maintenance, and absence of sufficient silt deposition to build up a new toe-slope within the lifetime of the tree deflector, this method of control was not successful on this type of stream. A more permanent type of toe protection, such as stone riprap that is not subject to damage by heavy ice floes, is required.

Although this type of installation was not considered successful on the Winooski, owing principally to lack of maintenance, it has been used with success in other sections of the Northeast where there is little danger of ice damage and where the tree deflectors are properly maintained. On one such project, elm trees 16 inches or more in diameter were skidded into place, shingle fashion, along the top of the bank and cabled together. The whole string was then pushed over the bank with a bulldozer and anchored to "deadmen" buried in the field at 200-foot intervals. Gaps were filled with additional trees. Without suffering any appreciable damage, this type of deflector withstood a flood that overflowed the banks in some places. Another project, designed for the protection of a highway bridge, has successfully controlled erosion for several years. It has had annual inspection and maintenance, including the addition of trees as needed.

Stone-Filled Log-Crib Jetty (Wing Crib).—As an experiment, stone-filled log cribs were placed at the toe of a slope in order to deflect current and retard velocity and thereby cause deposition and prevent scouring below the normal water line (fig. 9). The cribs extended about 15 feet into the river at an angle of about 45 degrees.

Instead of causing deposition, however, these cribs caused an overfall and turbulence, with consequent destructive scouring on the down-

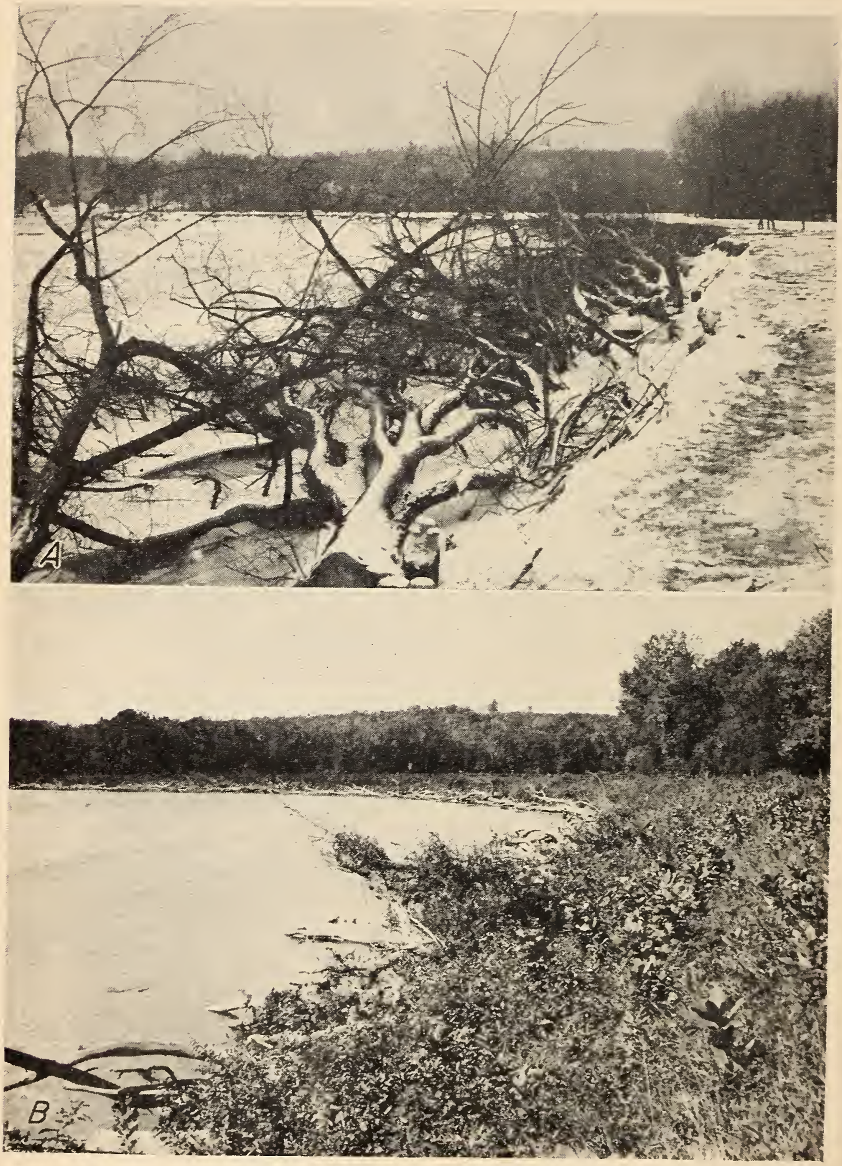

FIGURE 8.—Whole-tree deflector: *A*, Whole trees placed at toe of bank and cabled to log piles, 1938; *B*, same bank in 1941, after planting.

FIGURE 9.—Streambank protected by stone-filled log-crib jetties (wing cribs) supplemented by stone riprap.

stream side. This type of structure is more expensive than simple stone riprap.

PERMEABLE PILE JETTY.—Enough permeable pile jetties were installed to indicate that their effectiveness on a stream like the Winooski, which has a frequent and rapid rise and fall, is limited. As the river rises above the piles, the deflecting action is lessened and the turbulent water is apt to cut away the sediment deposited behind the jetty. Riprapping is effective in preventing this. Without riprapping, heavy ice floes may break the piles. Experience and judgment must be exercised in determining whether a jetty or system of jetties will give the desired protection more economically than riprapping or some other treatment. While the use of pile jetties did not prove very successful on the Winooski, there are sections in the Northeast where this type of structure may prove the most suitable and most economical method of bank protection when properly installed.

STABILIZATION OF FLOOD CHANNELS FORMED BY OVERBANK FLOWS

The design of economical measures capable of keeping the swollen, ice-filled stream from repeatedly breaking out of its normal channel and forming new channels through adjacent farm land was a major problem. This work involved also the repair of previous bank breaks and the protection of lands previously damaged by high water. The impact of ice and high-velocity floods subjected all control measures to the most severe test.

Temporary structures in combination with a wide belt of living trees were used instead of the more costly, permanent, and impermeable levee type of structure. The aim was to slow the current sufficiently to let the trees become established, and then depend upon the trees to exercise major control. Control measures consisted of: (1) Tree barricades along the main channel supplemented by log-pile check dams and buffer and filter plantings, (2) buffer and filter plantings at chute heads, and (3) stone-filled log cribs with buffer and filter plantings.

Tree Barricade and Log-Pile Check Dam with Broad Buffer and Filter Planting.—A temporary barricade about 7 feet high and 900 feet long was built on a section of the river where previous floodwaters had cut new channels through cropland (figs. 10 and 11).

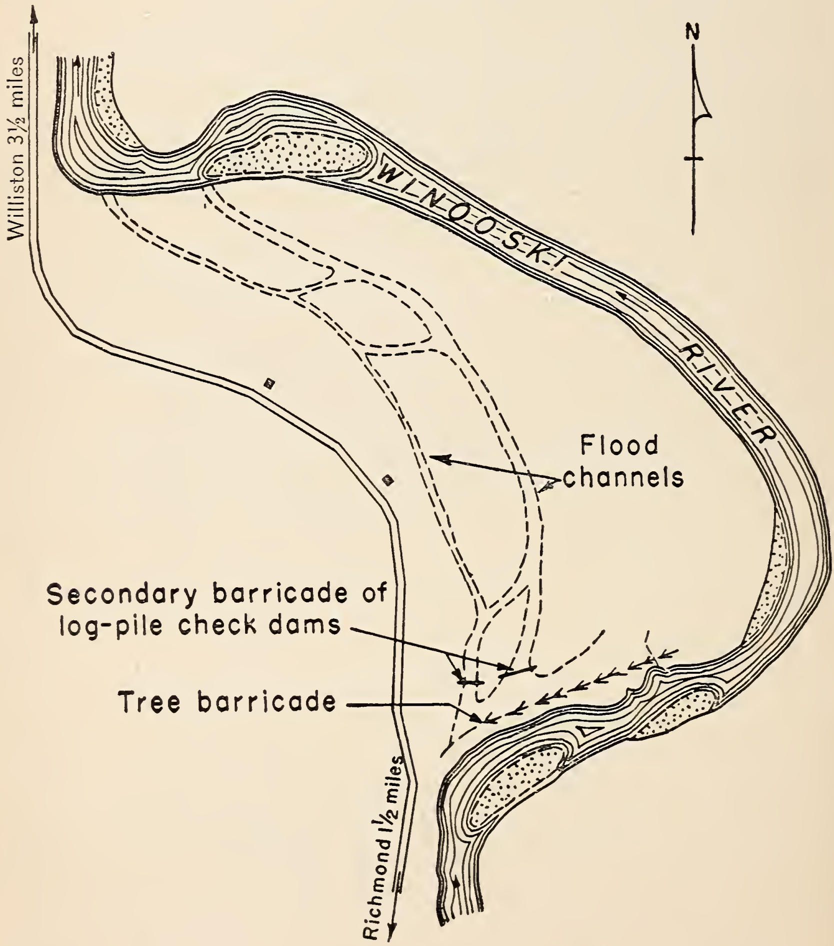

Figure 10.—Map of section of Winooski River showing channels cut by floodwater and location of tree barricade and log-pile check dams.

FIGURE 11.—New channel (foreground) cut through farm land by Winooski River during 1936 flood.

The main barricade consisted of large trees laid horizontally, cabled together, and anchored along its length to heavy concrete deadmen by cables. It was anchored at each end to rock-filled log cribs (fig. 12).

Secondary barricades consisting of log-pile check dams were constructed in the individual chute heads by driving two rows of piles and filling the space between the piles with brush and logs. A stone apron was constructed on the field side of the dam (fig. 13).

After 10 years, the timber in the check dams and in the main barricade had rotted. Trees which had been planted in a buffer belt grew well, however, and by the spring of 1946 they had attained sufficient size and density of stand to withstand a flood carrying heavy ice cakes. Although the flood flattened and damaged the trees (fig. 14), the plants later recovered. This belt of trees served successfully as a filter strip. It caused some sedimentation and thus protected to some extent the farm land beyond the strip. Not enough soil was deposited, however, to completely rebuild the riverbank. Further observation is needed to determine whether continued growth of the trees will adequately control floods and aid further in reclaiming the land damaged by flood flows.

It is essential that a dense sod of perennial grasses be maintained at the ends of the check dams in order to prevent end cutting. When land close to the end of the structure is plowed and cultivated, the disturbed soil is highly vulnerable to erosion. Floodwaters easily open a by-pass channel in such places (fig. 15).

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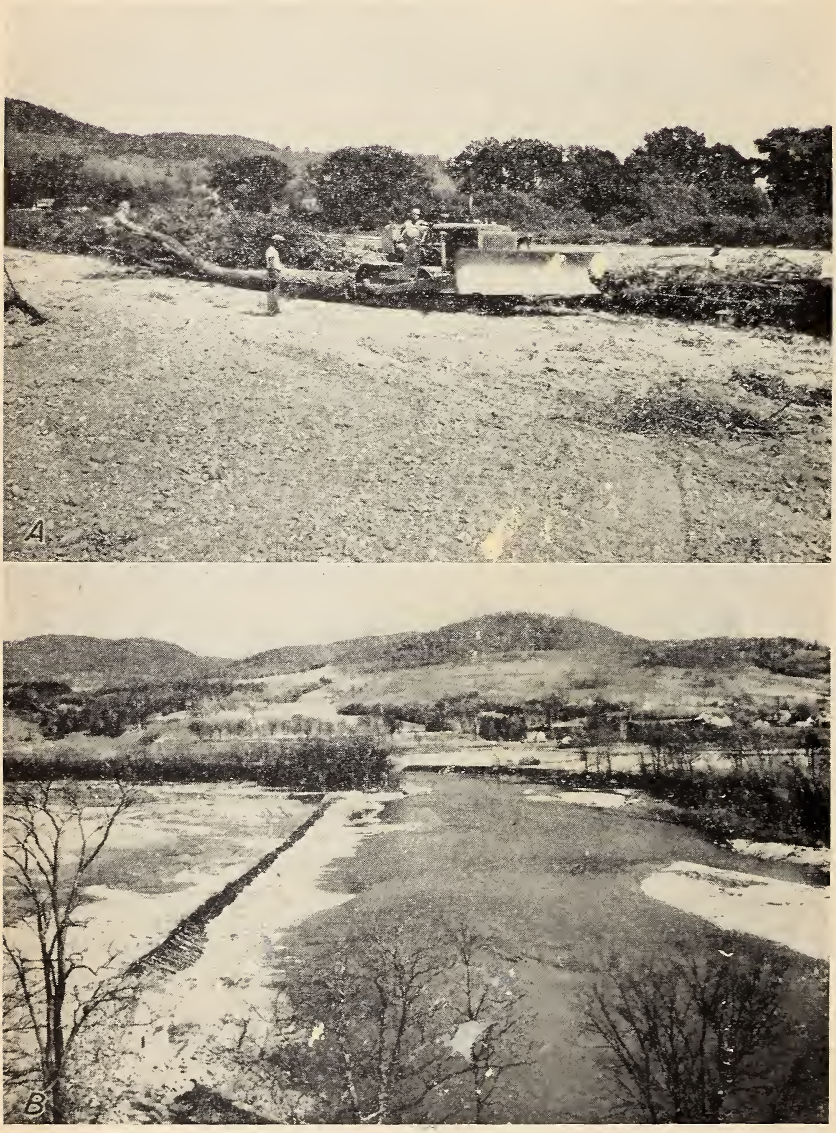


FIGURE 12.—Tree barricade across main chute. A, Trees are pushed into place by bulldozer and securely cabled together; B, completed structure showing rock-filled log crib at end (lower left).

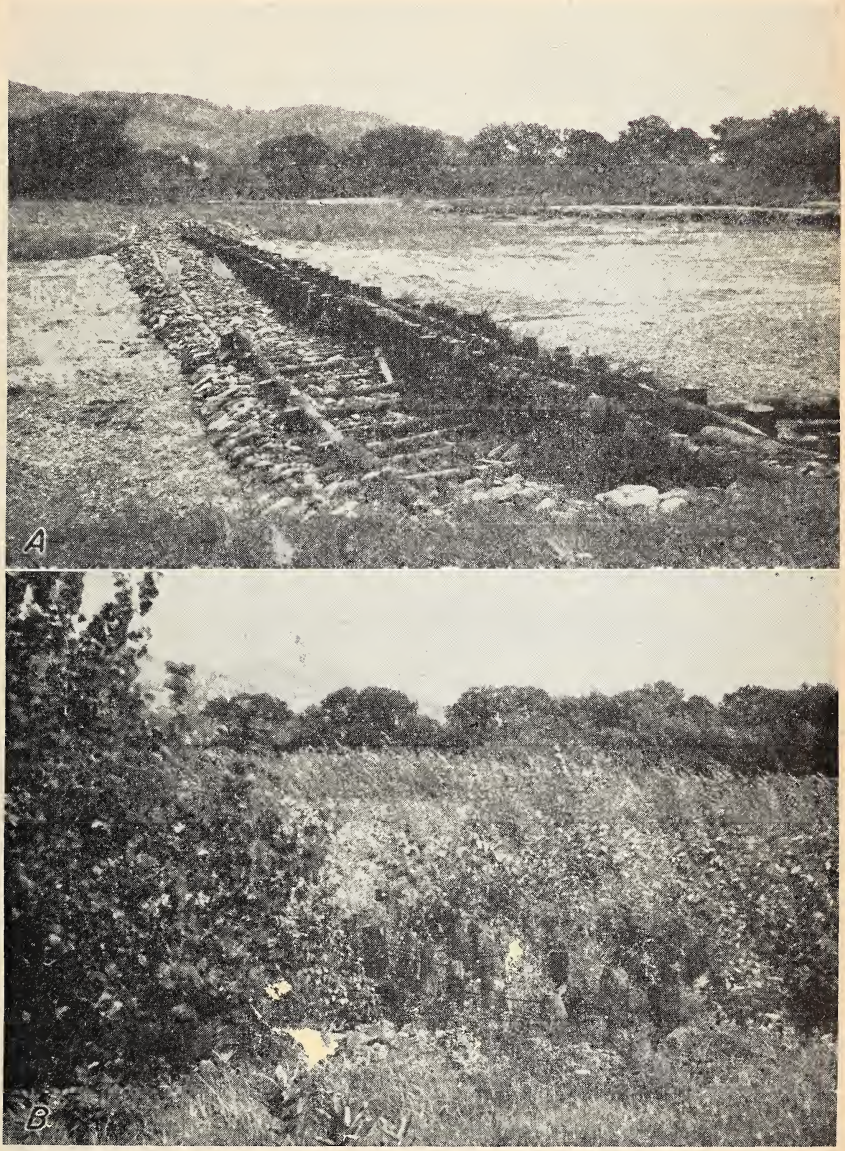
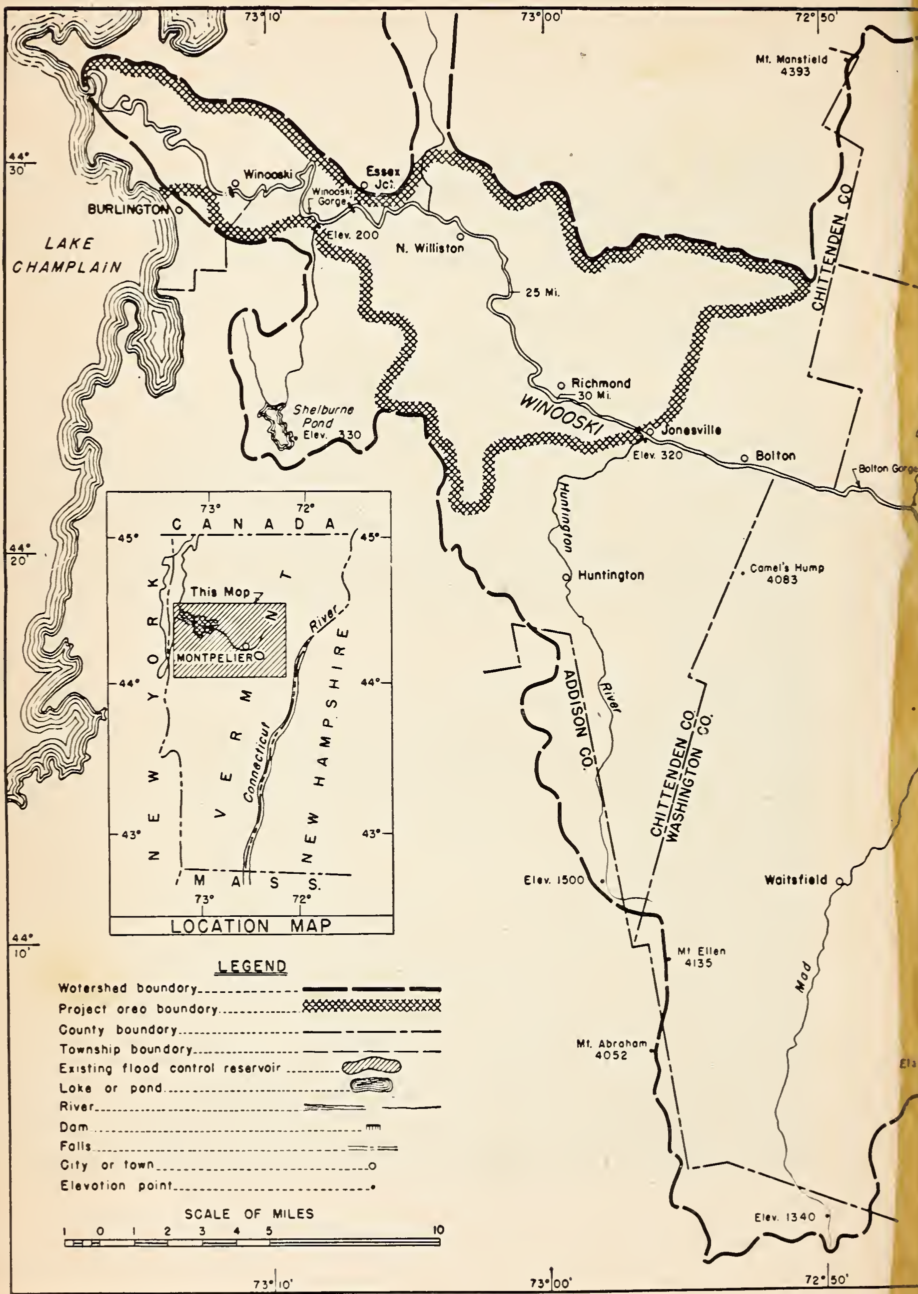
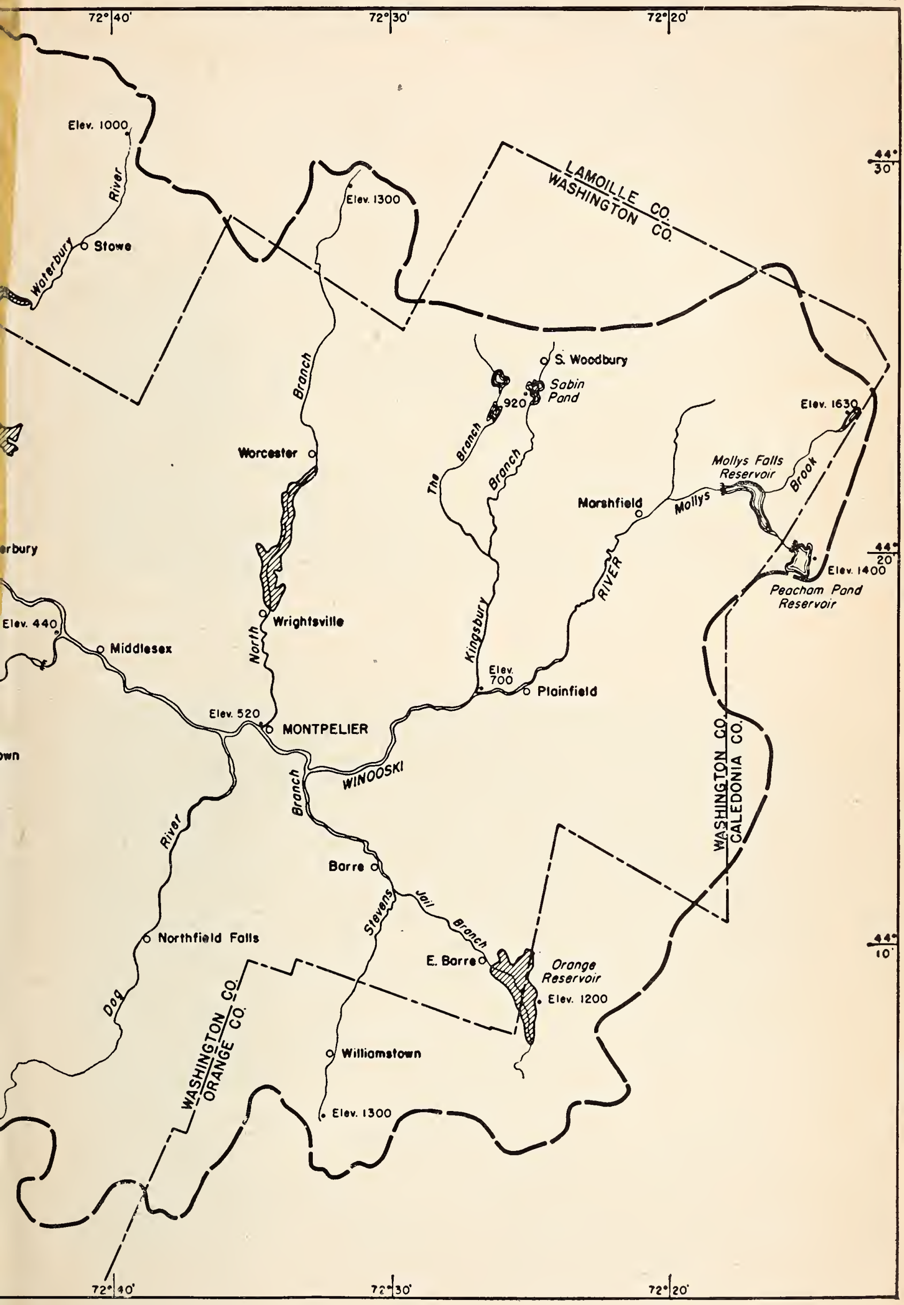


FIGURE 13.—Log-pile check dam constructed in new channel just below main barricade: *A*, Just after construction in 1938 showing stone apron; *B*, 4 years later showing growth of buffer planting.



Map showing location of Winoo[...]



treambank erosion project.

Map showing location of Winooski River streambank erosion project.

FIGURE 14.—Barricade and buffer planting showing temporary damage to trees caused by spring flood of May 13, 1946.

FIGURE 15.—New channel cut through plowed soil at farther end of check dam, 1946.

Buffer and Filter Plantings to Protect Chute Heads and Prevent Channel Changes.—Chute areas opposite bends in the stream and behind the barricades were planted to trees in a belt 200 feet in width across the chute head. The majority of these chutes were well drained except during periods of temporary high water. On the well-drained areas, plant survivals were consistently successful. Native willow and hybrid poplars were used. The spacing in the center of the chute area was at intervals of 4 feet, elsewhere 5 feet each way. Good initial stands developed, but the poplars later were greatly damaged by canker. Despite weakening of the poplar, the stands as a whole continued to give effective protection.

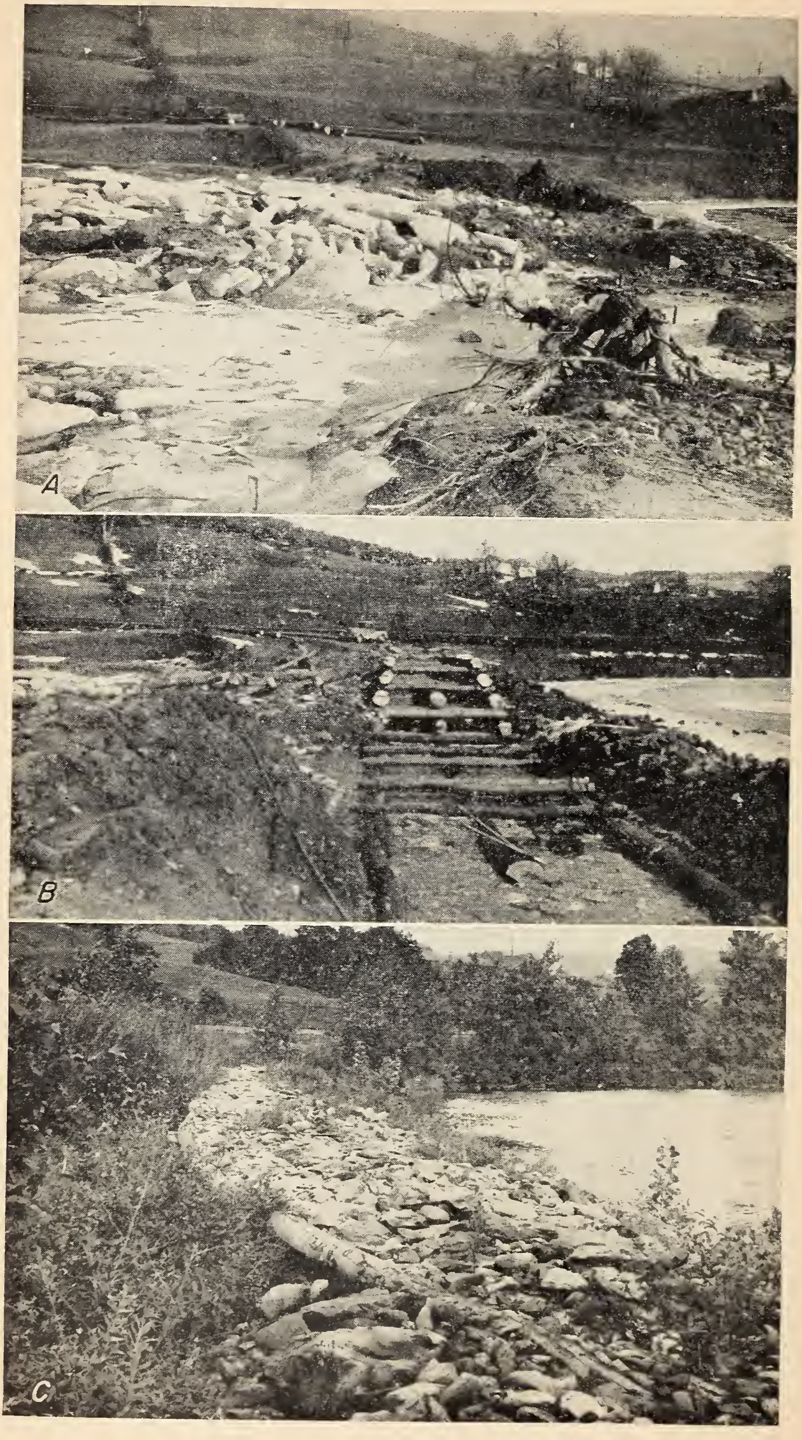
Excessive wetness in certain chute areas caused a heavy loss of plantings, especially poplar. On wet sites, purple-osier willow made better growth than did poplar or native willow.

The close-growing stands of trees forming the filter plantings slowed the movement of water, ice, and debris. The trees reduced the destructive force of the moving water and sifted out much of the debris, and served as filters behind the structural barricades across the chute heads.

Ice extensively damaged the chute plantings, stripping most of the limbs from the trees in one chute area that had been completely covered by stream-borne ice cakes. The trees recovered, however, and, in general, the effectiveness of the chute plantings was not seriously reduced. It was believed, however, that purple-osier willow would have been more satisfactory than native willow and that either of these plants would have been better than poplar. The willows suffered less breakage than the poplars, and recovery from injury was more complete. The young white willow trees withstood ice damage better than the poplars but future damage will probably be more severe as the trees become larger and more rigid. The greater resiliency of purple-osier willow made this plant superior to white willow. As time goes on, the superiority of purple-osier willow for chute planting will probably be even more marked. The tree willow, after further observation, may be found to be a useful plant in portions of chute areas farthest from the river channel. In such places the trees in time may form a rigid obstruction strong enough to keep ice and debris from reaching the crop fields.

Stone-filled Log Crib with Buffer and Filter Planting.—On the more severely damaged sections, stone-filled log cribs provided greater permanence of control than simple planting (fig. 16).

Trees were planted in a band 200 feet wide along the bank across the new channel parallel to the crib. The method of planting was similar to that mentioned in a later section under the heading, Installing Tree Barricades. The stone-filled crib greatly checked the velocity of the current and was still in good condition after 10 years. It had adequately accomplished the purpose for which it was constructed; namely, slowing the flow to the point where the trees could catch and hold the gravel and silt carried by the water. The crib will need minor maintenance until the logs rot, leaving only the stone. Additional plantings are needed on the field side and at the inshore end of the crib and in the channel in order to strengthen the buffer and provide the necessary protection after the logs rot. An adequate tree growth



will filter out the silt and further reduce the velocity of the flow. It is expected, as a result, that the water reaching the farm land will be clear and will flow slowly over the fields.

SUMMARY OF RECOMMENDED CONTROL MEASURES FOR STREAMS OF NORTHEASTERN UNITED STATES

The many mechanical and vegetative measures used to control streambank erosion on the Winooski River have been described in the preceding pages. These include measures that proved successful and those that failed or only partially succeeded.

For the benefit of farmers and technicians who are at work on this problem along the Winooski River and other streams of northeastern United States there follows a brief summary of those methods which have proved effective and appear to offer the best protection against streambank erosion. Some methods not used on the Winooski and others that have been given only a partial trial there but have proved successful on other streams are included in this summary of recommended practices.

Protection From Domestic Livestock

As stated above domestic livestock should be excluded from streambanks except where the animals must have access to the stream for watering. Watering places should be at points least subject to bank erosion. Where banks are eroding and lacking in cover, exclusion of domestic livestock from the banks is essential for erosion control.

Grazing on streambanks may be prevented by rearranging the land use in such a way as to take the field with the streambank out of pasture; or, in pastured fields, by fencing off the streambank.

The usual fence for cattle and horses is three or four strands of barbed wire strung on wood or steel posts. For sheep or swine, woven wire is needed. Electric fence is satisfactory as a temporary barrier for cattle and horses. It should not be used for year-after-year protection.

A living hedge of multiflora rose (*Rosa multiflora*) has proved successful in other areas, but owing to the fact that the limits of optimum growth had not been fully defined at the time the Winooski project was undertaken, the plant was not tried on this area. When fully developed, this type of hedge effectively turns all domestic livestock except unringed swine. It is permanent, attractive, and costs little to maintain. It furnishes useful wildlife cover and helps to conserve the soil.

While the living fence was not used in the Winooski demonstration, it is recommended for general application. Plants, usually 1-year-old seedlings, are spaced at 1-foot intervals in a single row about 6 or 8 feet back of the purple-osier willow planting on the bank. They

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Figure 16.—Stone-filled log crib with buffer and filter planting: *A*, Section of bank where the river cut a new channel across cultivated field, January 1937; *B*, crib under construction; *C*, completed crib 8 years later showing at left the growth of trees on field side of structure.

should be planted in plowed and harrowed ground or in a plowed furrow, and should be cultivated once or twice in each of the first two growing seasons. A light application of fertilizer in the planting furrow speeds growth. Since fertilization stimulates weed growth, additional cultivation may be necessary to assure survival of the rose plants. Unless one plans to cultivate well, it is better not to fertilize. Three to five years are required to develop the rose hedge as a fence. The hedge attains a height of about 8 feet and about the same width.

All fences should be located 6 feet behind the necessary willow plantings and at least 10 feet back from the shoulder of the bank.

Combination of Protective Measures Most Effective

Except where chutes have formed and at points opposite the inflow of sizable tributaries, some combination of bank sloping, stone riprap of the toe, brush matting, and shrub planting is recommended. Where the bank is not subject to undercutting, treatment by means of sloping, brush matting, and planting without riprap may suffice. This would apply where currents are offshore or the stream is small and not very deep. In these cases, erosion is usually due to cattle trampling and grazing. By removing this cause, treatment may be effective with only sloping and vegetative treatment. The toe of the slope should be protected by stone riprap or some other permanent type of mechanical structure where the bank is likely to be undermined.

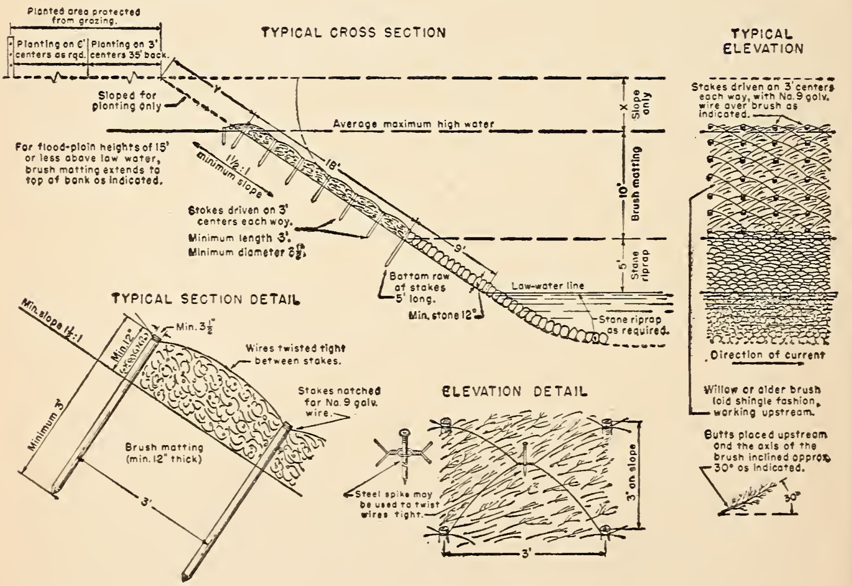

Figure 17.—Construction details of stone riprap and brush matting.

Figure 17 shows a typical plan for bank sloping, hand-placed riprap, and brush matting to be placed on the bank above the riprap to protect the shrub planting.

Methods of Bank Sloping

All material excavated from sloped banks should be deposited on the adjacent field and either spread out or made into a properly designed and constructed dike. In either case, the fresh soil should be planted to prevent erosion by high water. Bank material should not be pushed into the stream or against the banks, as high water will carry the soil downstream and create erosion problems on farms at lower points. On low banks and where the water is shallow, the banks can be sloped with a bulldozer or scraper. On high banks, a dragline or back hoe is necessary to do the work satisfactorily. Where vegetation is to be used for the bank protection, the angle to which the bank should be graded will be determined by the type of material in the bank. The recommended slopes for different soil types are:

Soil:	*Slope ratio*
Heavy clay	From 1:1 to 1¼:1
Medium texture	From 1½:1 to 2:1
Sandy or gravelly	From 2:1 to 4:1

The Use of Riprap

A carefully placed layer of stones and boulders, generally known as "riprap" is one of the most common and effective methods of streambank protection. It is applicable under most conditions where bank erosion occurs. The limiting factors are availability of stone; difficulty and expense of quarrying, transporting, and placing stone; and the large amount of material needed where streams are deep.

For successful riprapping the toe of the riprap must be firmly established. If the stream is shallow and has a hard bottom, this is not a serious problem. If the stream bottom is soft and unstable, failure often results. The tendency is to neglect the preparation of an adequate foundation for the bottom course of stone. As the weight increases with the placing of higher courses, the pressure on the bottom course increases and the foundation fails, especially when the toe of the bank is scoured by the stream. As a result, most of the riprap slides into the stream. Soundings should therefore be made and cross sections of the stream bed should be plotted before you start to place riprap. Make sure the toe of the slope is protected and that an adequate foundation is provided.

Large stones are best for riprapping. Although small stones are easy to handle, they are easily gouged out by ice and carried away by swift currents. Stone should range from "one-man" size to larger. It should be dumped on the bank where it can be conveniently barred into position.

Steep banks should be sufficiently sloped so that the pressure of the stone is mainly against the bank rather than against the stone in the lower courses. The proper slope for successful riprapping depends upon the kind of bank material and should never be steeper than 1:1.

Riprap should extend up the bank far enough to give adequate protection. This point is usually 2 to 5 feet above the normal water line, or the low point where vegetation naturally grows. On sharp curves or where valuable property is endangered, riprap should be extended to the top of the bank.

Although riprap, when properly placed, gives fairly permanent protection, it requires maintenance. Riprapped banks should therefore be inspected regularly, particularly after every high water. Necessary repairs should be made promptly.

Planting Practices

Species recommended for streambank planting are purple-osier willow and either red-osier dogwood or silky cornel (*Cornus amomum*), depending upon locality. Red-osier dogwood is probably best in New York and New England, while silky cornel is best for areas farther south.

In planting dogwood, one row of plants is placed at the bottom of the planting area along the edge of the riprap. Seedlings, rooted cuttings, or fresh hardwood cuttings, spaced 2 feet apart, may be used, with preference in the order named. The remainder of the bank and a strip on top of the bank between the shoulder of the bank and the protection fence are planted to purple-osier willow. Here, also, spacing should be 2 feet apart, both in rows and between rows. The position of plants should be staggered from one row to the next. Rooted cuttings are preferred over fresh cuttings.

The sloped banks should be planted before the brush matting is applied. Ideally, all planting should be done in the spring. However, for banks sloped and riprapped in the summer and fall, this would delay planting and brush matting until the next year. In the meantime, the high water of late winter would probably wash out the exposed raw bank. Hence, planting should not be long delayed.

If possible, the banks should be sloped and riprapped in time to permit planting in April, May, October, or November. Planting may be done in the summer months if such timing is not feasible.

All leaves should be stripped from summer-planted stock. The cuttings should be moved promptly to the planting site and set without delay to avoid excessive losses of planting stock. There is a great advantage in having the source of planting stock convenient to the job.

Application of Brush Matting

A mulch of hardwood brush should be placed over the exposed soil as soon as possible after the bank is planted. Speckled alder and purple-osier willow are preferred, but any convenient brush may be used. The brush is laid shingle fashion with the butt ends pointed upstream. It should be trimmed, if necessary, to lie flat on the bank. The mulch should be 4 to 18 inches thick, depending on size of stream and quantity of ice and bed load.

Secure the mulch so it will not float away. Stakes driven at an angle and crossing each other in pairs may be all that is needed on small streams. The stakes are 3 feet long, placed at about 3-foot centers. On streams like the Winooski, stakes should be driven straight in and the mulch should be held in place by lacing galvanized wire between the stakes in a diamond pattern (fig. 17). A tight lacing will be assured if the stakes protrude a few inches above the brush before the wire is attached. The stakes are later driven in deeper. This tightens the wire and binds the mat firmly.

Applying alder brush in the matting between mid-September and the time the ground freezes gives the ripe seeds that fall on the bank opportunity to grow into plants that will be a desirable part of the living cover.

The Use of Buffer and Filter Plantings

Areas in and behind chutes and opposite the confluence of sizable tributaries need larger plantings than those used for bank control. A width of about 200 feet is recommended for woody plantings to provide a buffer and filter during periods of high water. Although these "defense-in-depth" plantings may cover some good farm land, they protect much larger areas of land from damage.

Purple-osier willow spaced from 4 to 5 feet between plants and rows is recommended for buffer-filter plantings. Other species of plants, including trees, may be used in portions of the planting area farthest from the stream channel. Plantings should always be made in the spring.

Maintenance of Plantings

No streambank conditions are permanent. The structures installed in connection with plantings deteriorate, and the plant cover itself is subject to change from destructive physical action and through natural laws of plant succession.

The purple-osier willow and red-osier dogwood recommended for stabilizing streambanks will in time be displaced naturally by other species. Trees and other plants seed in and crowd out the planted ones unless deliberate steps are taken to maintain conditions favorable to the planted species.

All streambank plantations of purple-osier willow and red-osier dogwood should be inspected annually, preferably in early spring as soon as possible after the ice and high water have gone. Damage can be easily spotted and appraised at that time.

Repairs should be made in the spring. These include: (1) Replanting, (2) removal, and (3) lopping. Bare places should be replanted with new seedlings, rooted cuttings, or fresh cuttings obtained from a source of supply located conveniently near the planting area. If soil conditions are favorable, small bare areas can be revegetated by layering the branch tips of neighboring live plants. Both purple-osier willow and red-osier dogwood reproduce by layering.

Undesirable and unwanted plants should be cut out. These include all tree species that have seeded in among the shrubs. Cutting will satisfactorily eliminate them, provided it is done before the trees are 2 years old. Only by continuous vigilance can the best cover be maintained.

Due to very favorable growing conditions or to hybridization, purple-osier willow may grow too large and rigid for effective bank protection and should be cut back. Plants with stems more than an inch in diameter should be lopped off. They will then sprout new stems to fill in the open spaces. The keynote for bank maintenance is: *Don't put it off!*

Blanket Protection With Large Trees

A pervious revetment made from trees cabled together and anchored by deadmen buried in the bank is probably the cheapest form of protection, at least as regards cost of material. For streams carrying a

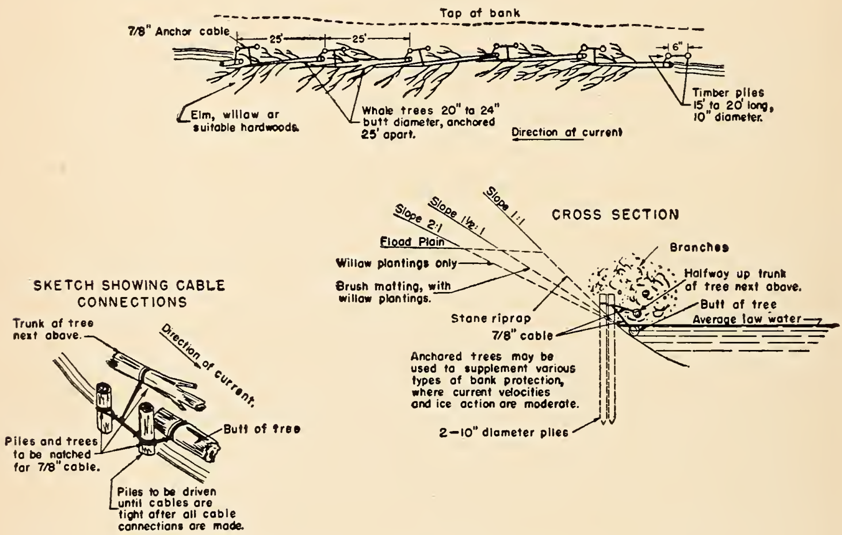

Figure 18.—Anchored tree deflector.

heavy bedload, this and various types of pervious jetties or revetments are designed to slow the velocity of current next to the bank and cause deposition, which results in a more impervious covering and prolongs the effective life of the protection. The life of this type of structure depends mainly upon the size of material used—the larger the trees, the longer the life. Effectiveness and life are also dependent upon strength of cable and stability of anchor. When this type of control is used on small streams, the effect of reduced channel width should be allowed for in designing channel capacities. Constant inspection and maintenance are essential. Breaches that occur when tree limbs break off or rot should be mended by adding trees.

Placement of Tree Deflectors

Tree deflectors, like tree "blankets," are pervious velocity-reducing structures (fig. 18), used chiefly where the water at the toe of the slope is very deep. They are considerably less expensive than riprap. Those installed on the Winooski were usually supplemented by brush

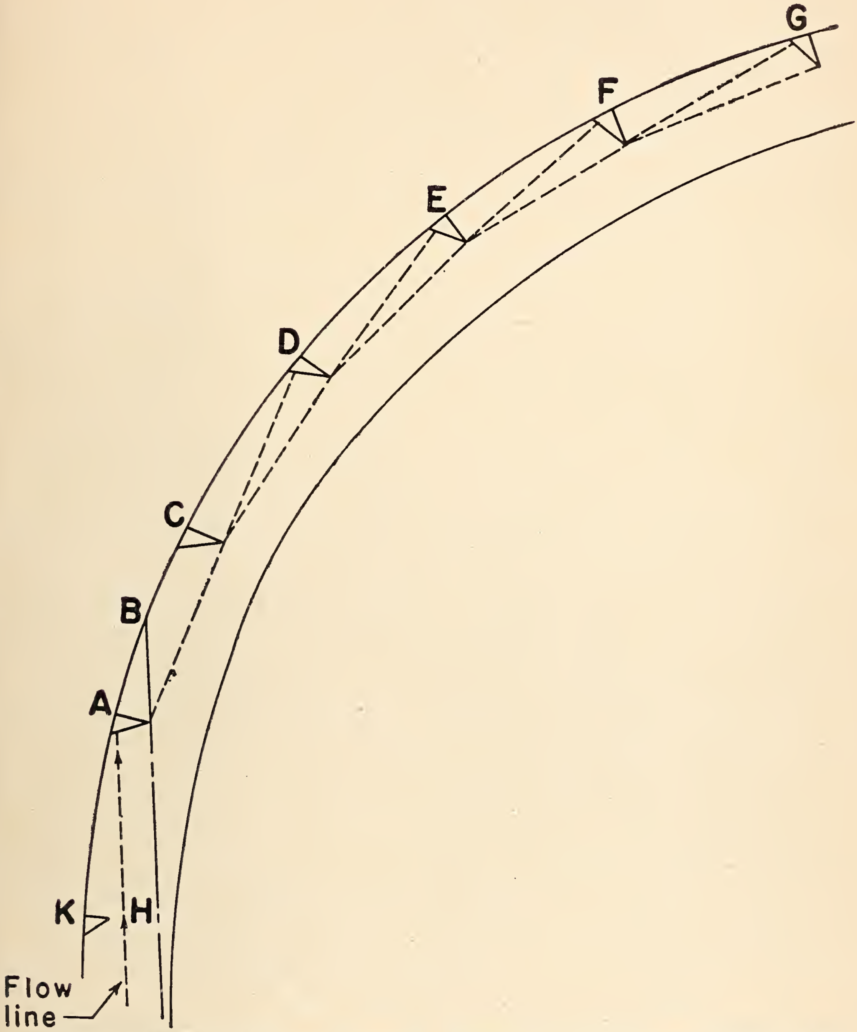

FIGURE 19.—Method of locating jetties. Point *A*, location of first jetty, is the intersection of the flow line and the eroding bank. Jetty *C* is located by drawing *HB* parallel to the flow line and across the toe of jetty *A*. *AC* is twice *AB*. Jetty *D* is located by projecting a line across the toe of jetties *A* and *C*. The remaining jetties are located the same as *D*. Supplementary jetty *K* is located *AC* distance upstream from *A*.

matting and protective planting. Some slack should be provided in the anchoring cables to allow the trees to rise and fall with changes of water level. As with other types of bank protective structures, the upstream end of the deflector should be securely tied to some permanent or stable section of the bank. Figure 18 illustrates the use of timber piles for anchoring the upstream end where a ledge outcrop or some stable structure like a bridge abutment is not available for this purpose. General deterioration and the impact of flood debris and ice will eventually rob these trees of their fullness and small limbs, leaving single large limbs which create eddies in the current. These eddies may accelerate bank erosion at local points. When this occurs, damaged trees should be replaced. Frequent inspection should be made to determine the condition and effectiveness of the tree deflectors.

Construction of Jetties

Jetties are used primarily to deflect the current away from the banks. They may be built of large stone, stone-filled cribs, piling, or brush and stone. The location, number, and spacing of jetties are determined mainly by the direction and impact of the stream current and the curvature of the bank (fig. 19).

Jetties are particularly useful where water adjacent to the bank is more than 4 feet deep and where the velocity of current is too high to assure protection with anchored trees. As the depth of water increases, the cost of riprap for toe protection becomes excessive and jetties become more economical than riprap.

Figure 20 shows a typical plan for a semipermeable pile jetty, with dimensional details for different bank-jetty angles. Other types of jetties that have been used are wing-crib jetty (fig. 21) and the wire-bound rock or sausage type (fig. 22).

Studies of models and observations in the field indicate that there is a limiting degree of curvature at which jetties are economical. Since the spacing of jetties in a properly designed jetty system decreases with sharpness of bank curvature, a point is reached where more material would be required for jetties than for some type of continuous structure. Also, as the flood stage rises, the current may shift its direction of impact on sharp curves and strike the bank between jetties, thereby reducing the effectiveness of the jetties. Consequently, for bank curvatures exceeding 30 degrees (radius less than 200 feet), it is safer and more economical to use continuous protection.

Building Stone-Filled Log Cribs

The purpose of stone-filled cribs (fig. 23) is to arrest velocity through a recently eroded channel, thus causing slack water and silt deposition on the flood plain below the structure.

Only logs of the most durable timber available locally should be used. Less expensive structures, such as tree barricades, should be used where conditions are not so severe. Structures of this nature are usually necessary to tie less expensive structures into banks.

The excavation for the crib is carried to a gravel or other relatively stable foundation. The crib is built without a floor in order that the stone fill may settle and form its own cut-off wall if undercutting

TABLE OF VARIABLES
FOR VALUES OF ∝ FROM 30 TO 45 DEG'S.

∝	A	B	C	D	E	F	G	No. of piles
30°	4'-0"	6'-4'	16'-0"	13-10"	9'-0"	36'-0"	32'-0"	19
35°	3'-6"	5'-4"	14'-0"	11'-6"	11'-0"	35'-0"	31'-6"	21
37½°	3'-3½"	5'-0"	13'-2"	10'-4"	13'-0"	36'-3"	33'-0"	23
40°	3'-1½"	4'-6"	12'-6"	9'-6"	13'-0"	34'-4"	31'-2"	23
45°	2'-10"	3'-11"	11'-4"	8'-0"	5'-0"	34'-0"	31'-2"	25

NOTE: Dimensions shown are constant, and horizontal unless otherwise noted.

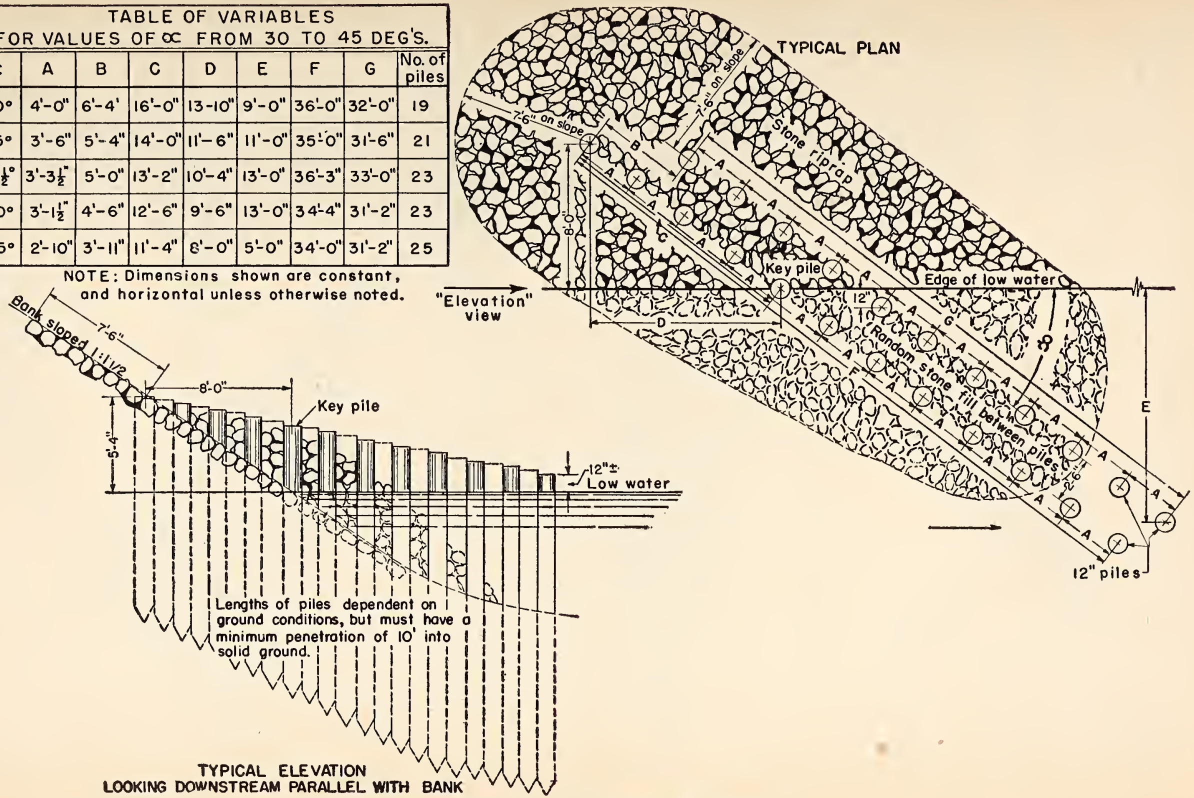

FIGURE 20.—Semipermeable pile jetty.

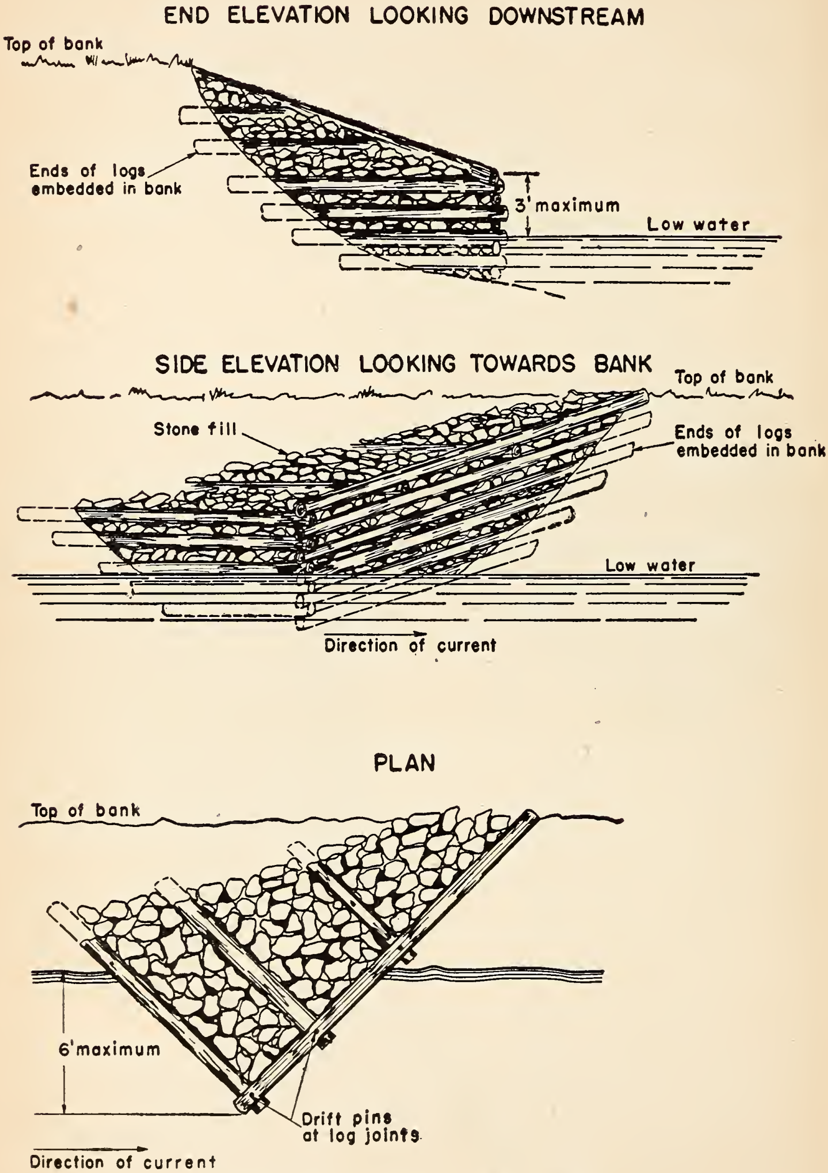

FIGURE 21.—Typical wing-crib jetty.

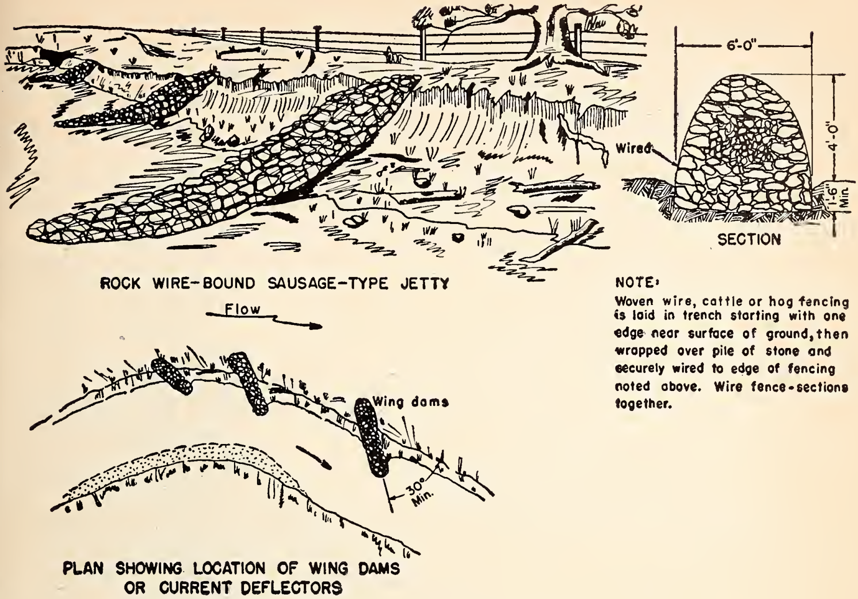

FIGURE 22.—Sausage-type jetty.

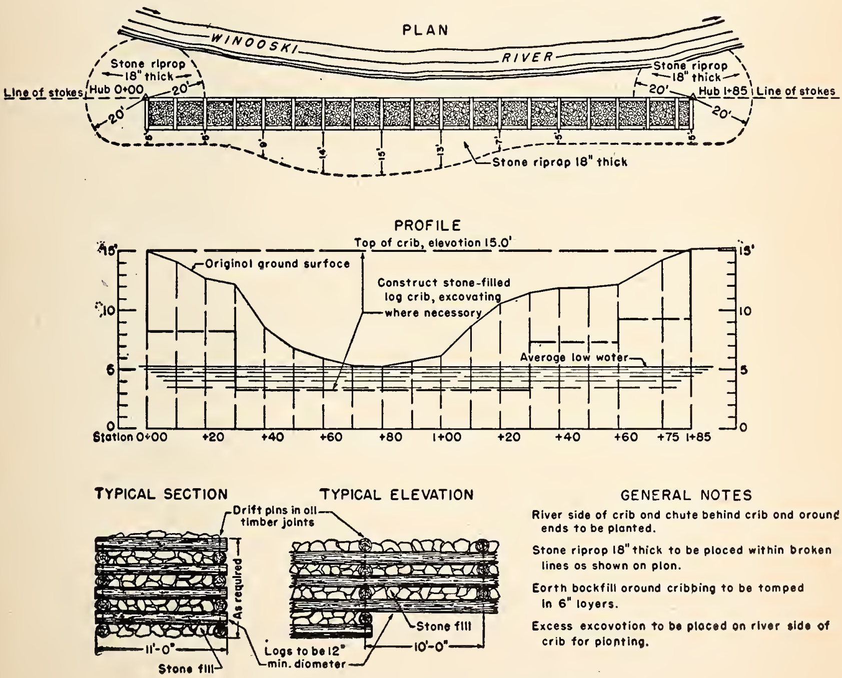

FIGURE 23.—Stone-filled log crib.

occurs. The height of the crib is maintained by adding stone at the top. To reduce ice damage, the upstream face of the crib is built with a batter of 1:1. All logs are notched and pinned together with ⅝-inch pins driven into ½-inch bored holes. The crib is designed with sufficient width to permit trucks to dump stone directly into it. A stone apron should be placed on the inshore side of the crib to prevent undercutting.

A wide band of trees should be planted parallel to the bank on the field side of the crib as a permanent barrier to aid in arresting flood velocities. Over a period of years the silt deposited from slack water should build up a barrier to a height comparable to the original bank.

A stone-filled crib may also be used to protect the toe of bank slopes (fig. 24).

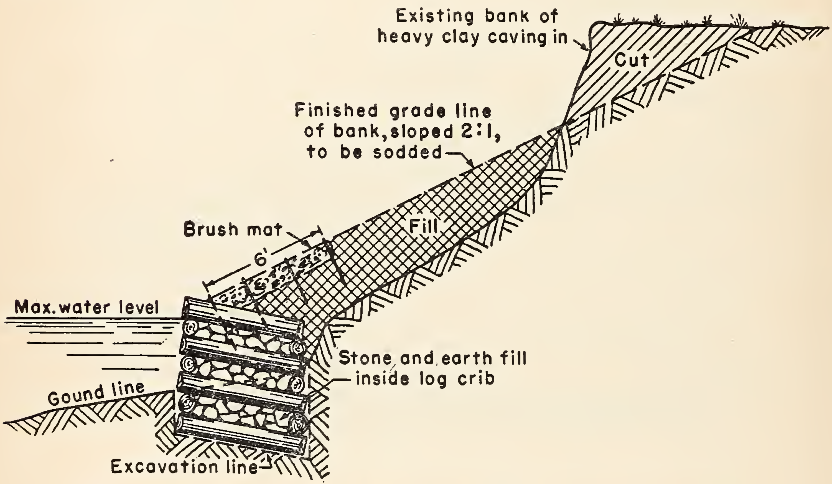

Figure 24.—Stone-filled log crib used for toe-of-slope protection.

Installing Tree Barricades

Tree barricades (fig. 25) are particularly applicable where the river is threatening to form one or more new channels and where conditions are not severe enough to warrant the construction of a stone-filled log crib, or where the length of bank needing protection makes the expense of a stone-filled log crib prohibitive.

Although the main barricade is pervious, the upstream end of the structure is made impervious for a sufficient distance to provide a substantial tie into the original streambank. This portion of the barricade consists of standard stone-filled log cribbing. The barricade proper consists of whole trees piled longitudinally and closely lapped, tops and butts, with a filler of small trees, brush and debris logs. Trees, brush, and logs are securely wrapped at 20-foot intervals with ¾-inch steel cable into a fairly compact mass. Each cross wrapping is clamped to a steel cable placed along the full length of the barricade. This longitudinal cable in turn is anchored by cables to concrete deadmen located at the upstream and downstream ends. Barricades of this type are extremely buoyant, and the heavy wrappings and firm anchorages are essential in order to prevent high water from tearing the barricade loose and carrying it off.

The barricade may be protected from ice damage by two different methods: (1) Anchoring trees of approximately 6 inches in diameter

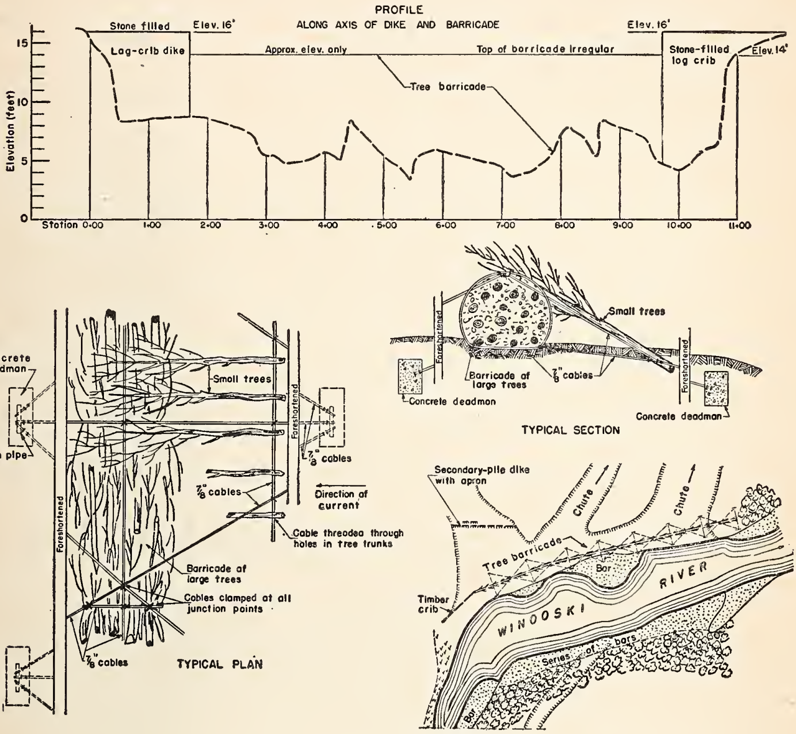

FIGURE 25.—High-water tree barricade.

at their butt ends to a cable placed in a trench 18 inches deep, with the tops of the trees lying on top of the barricade and anchored to the longitudinal cable; and (2) back-filling the stream side of the barricade with gravel from the river channel, using a bulldozer. The second method is cheaper and more effective and has the added advantage of deepening the river channel, thus increasing discharge capacity.

This type of structure requires continual maintenance. Repairs are made by removing the cable clamps and drawing in sound trees and brush to rebuild the barricade, then replacing the cables and clamps.

MAINTENANCE

Continued maintenance of completed erosion-control works is essential to avoid future, and possibly greater, damage later. In planning for the maintenance of streambank erosion control, it is important to keep the following points in mind: (1) Control measures, once adopted or installed, are not automatically permanent, and it is usually economically impractical to attempt to establish absolutely permanent controls; and (2) the nature of the maintenance differs in different parts of the general drainage area owing to the extremes in physical characteristics of rivers and creeks. Because the vagaries of currents at flood or high-water stages cannot be determined precisely in advance, the amount and intensity of treatment needed cannot be completely foreseen at the start. It would be impractical, if not impossible, furthermore, to predict the length of time any recommended streambank-control measure will safely function without maintenance.

On-site appraisal of conditions is necessary for a proper understanding of maintenance needs. It is not necessarily the extremes of flood or abrasive action of ice and other water-borne debris that cause protective measures to lose their effectiveness. Small, never-idle currents excavate the soil under blanketing shrubs or shingling stones, forming pockets and causing banks to cave. When breaks occur, the erosive force increases. Careful examination of plantings and structures during the first few years following installation will disclose points of weakness, and sections likely to give way can be strengthened. The application of strengthening measures enables the entire system of controls to function as planned. The adage: "A chain is no stronger than its weakest link" may be paraphrased to apply to streambank-erosion-control measures: The effectiveness of a streambank-erosion-control system depends on the maintenance of each control measure.

ORGANIZING STREAMBANK EROSION CONTROL

There are many points on a stream where simple measures, with a little upkeep, will adequately protect the streambank against erosion for many years. Successful erosion control and reduction of flood and sediment damage, can seldom be achieved, however, on an entire stream system or watershed by erecting structures and planting on a piecemeal or hit-and-miss basis. These are community problems, involving organization, planning and concerted effort on the part of all persons affected by streambank erosion, with the aim of getting the work done.

No two flowing bodies of water are alike. Some large rivers carry great volumes of water and heavy bed load; some small creeks may have relatively low velocities and flood stages, and small bed loads, or vice versa. All streams tend in some degree to erode their banks and carry the soil downstream. Streambanks anywhere in the drainage area, beginning at the point where the first unprotected soil is touched by the current, may furnish the sediment that builds up stream beds and reduces channel capacities farther downstream. This forces floodwaters out of normal channels and enables them to spread their load of gravel and boulders on fertile fields. Soil deposited in channels induces a rise in water levels and creates drainage problems. The sediment from streambank erosion may also move on down to a reservoir or a harbor, where costly dredging operations are needed to keep pace with upstream erosion.

Caving banks at any point on a stream are a constant threat to the permanence of downstream control structures. Even streambank control at one point, undertaken independently of measures elsewhere, may increase the hazard of erosion and flooding farther downstream. The planting of bands of shrubs and trees at one place, for example, may retard and divert floodwaters to adjacent unprotected fields previously free of flood currents or debris stranded by high water. Occasional or piecemeal control may not in all cases lessen the bed loads of sand and gravel torn from eroding banks. While stream-channel clearance or straightening may temporarily solve one farmer's problem, the accelerated currents resulting from such work may increase the danger of streambank erosion on downstream farms. Failure of all affected property owners to cooperate in a complete and unified control program, therefore, may make it impractical or impossible for an individual to obtain adequate control by himself.

The erosion problem is not confined to the stream and its immediate vicinity, but takes in the entire watershed. Grains resulting from piecemeal streambank control are small and short-lived when farm lands are cultivated in such a way as to allow furrows and crop rows to become downhill gutters, and when the watershed as a whole is denuded of its vegetation. Conservation treatment, therefore, must be applied to the upland slopes between streams before the greatest benefits of a streambank erosion and floodwater control program can be obtained. This calls for the joining together of all landowners in a watershed in a common effort, each doing that which is necessary on his own land to slow down rushing surface water, and each using the soil so that it will absorb the largest amount of rainfall. Each farmer on the creeks and rivers must aid in getting the bare soil of streambanks covered so that both his own land and that of adjacent farms may be preserved for sustained use.

From the standpoint of benefits to the community in general, plans for the control of water and soil erosion for the entire watershed, in which control of streambank erosion is but a part, are needed. The conservation program and general operational plan should recognize that mutual effort is required to attain the major objectives of streambank control. In this work the individual landowner and the town, county, State, and Federal governments all have responsibilities. Accomplishment is dependent upon the cooperation of all landowners and land users. Neglect of needs by even a small minority can result in the partial or complete failure of any streambank-erosion-control project.

Scheduling the Operations

Organized cooperation aids in scheduling the control operations for most effective work. Riprap on banks should be laid during months when water level is lowest, and many other types of control structures can be built to best advantage during the winter months or at low-water stages. Planting of vegetation is seasonal. Shrubs should usually be planted in the early spring, following recession of high-water stages.

In order to keep construction costs down, work once begun must be completed before the rushing floodwaters wash away the work under way. Some portions of banks are more erodible than others, and upon them may depend stability of other portions of the bank. In order to complete the job on time and to allow for orderly progress of work, it is important that all necessary machinery, equipment, and materials be on hand when needed.

Planning for the total control operation assures the proper timing of different jobs on one or more farms. Such planning makes it possible to give the necessary priority to jobs which protect work previously done under a progressive program. On many rivers, for example, riprap is required in such great quantities that an individual farmer is unable to haul and place the stone in time to safeguard the structure from impending floods. As the result of increased stream turbulence and bank erosion, much of the completed work may be destroyed and would have to be repeated. In such cases, planned cooperative action helps to prevent delays in construction due to lack of materials or shortage of labor, and assures adequate resources to complete the work during favorable water stages.

For large streams with high banks, the type of controls needed may require the use of heavy equipment and machinery. Where such equipment is not owned by an individual farmer or is not readily available to him, it can usually be obtained through group action.

Working Through Soil Conservation Districts

Soil conservation districts are logical organizations to handle the planning and operation of a streambank-erosion-control undertaking. They are usually political subdivisions, and are organized on a voluntary community basis to deal with problems of land use, soil erosion, and water conservation. Their programs and plans call for the application of conservation measures to every acre within their boundaries.

The mapping of all land within a district gives district governing bodies the great advantage of the basic physical data they need for complete and sound planning. With the map they can locate eroded areas and areas threatened with streambank erosion. Farmers and technicians working together prepare the plans for individual farms that set forth the measures needed to control erosion and to prevent and remedy actual and potential damage to fields by floods and high water tables.

Many districts own and operate heavy equipment; others secure such equipment through cooperative arrangements.

Direct cooperation of State road commissions and other agencies with districts insures effective united efforts in control of streambank erosion.

COSTS AND BENEFITS

The cost of controlling a particular bank may be greater than the value of adjacent fields, but if the bank is left unprotected, the ensuing floods may endanger many downstream acres and improved properties. Control measures thus protect downstream owners, and benefits are usually not confined to the owner of the land on which the work is done. For this reason, the cost of streambank control should be borne, where possible, by all who benefit from the program.

Continued successful use of farm land may depend directly upon streambank-erosion control. Eroding streambanks threaten continued use of adjacent fields. Increased deposition in stream channels causes flooding and in time turns low-lying and well-drained lands into fields with imperfect drainage and limited use.

In some measure, however small, the public in general is affected by the effectiveness of streambank control. When good farms are saved from erosion damage, they contribute to economic and social welfare. Although the individual landowner has most at stake for the present and immediate future, the public interest is broader in scope and extends into the distant future. This interest includes protection of the land for production and as a tax base, maintenance of roads, protection of public utilities and municipal and industrial improvements, and maintenance of harbor facilities.

NEED FOR RESEARCH AND TESTING

Changes in runoff and flow characteristics, increased sediment loads brought about by changes in land use on a watershed, and intensive agricultural use of flood-plain lands are the principal causes of accelerated bank erosion. Deposition of eroded materials in channels creates additional problems. Factors which influence the degree of erosion are stream gradient, stage of flow, curvature of stream, amount and character of sediment load, bank cover, and bank characteristics. The relative effect of each of these factors on a particular stream or section of stream must be considered in the development of stabilization measures.

Much knowledge exists on how to control streambank erosion. Through trial and error, information has been obtained on the structures and bank treatments that may safely be used under different conditions. Because of the many factors influencing erosion, however, more research is needed, especially in the following fields: (1) Extent, rate, and causes of streambank erosion; (2) most effective methods of controlling erosion, including costs; and (3) maintenance requirements, including methods of extending the life of structures and plant cover. There is urgent need for investigative study designed to correlate and integrate accepted designs and to determine by test, in terms of durability and costs, the structural designs that are most effective. Despite the knowledge gained on the Winooski and in other areas, much more needs to be learned about bank-stabilization methods suitable for this area. The presently accepted methods and other methods of promise need study on streams having characteristics differing from those of the Winooski.

Bank stabilization constitutes a major item in the conservation program of many soil-conservation districts in the Northeast. Federal and State conservation agencies are being asked to supply technical assistance in the planning and installation of bank-protection measures. There is, accordingly, a need for practical criteria or "rules of thumb" that can be used by field conservationists in planning streambank-erosion-control measures and as guides in designing buffer structures and other treatments.

APPENDIX

Extent and Frequency of Floods on the Winooski River [3]

An analysis has been made of discharge measurements to determine extent and frequency of floods on the Winooski River since control works were installed and to determine effects of upstream flood-control dams on flood and normal stream stages. Floods and high-water stages on the Winooski result from rapid runoff of melting snow and excessive rainfall. High stages from snow-melt occur regularly every year, usually about the second week in April. Floods from excessive rainfall generally occur in the fall. Floods resulting from excessive rainfall are less frequent than those resulting from snow-melt, but flood records indicate that they are more severe.

Because of rapid runoff from headwater tributaries, floods exceeding channel capacities in the lower meandering valley sections, where bank-erosion-control measures have been installed, occur frequently. Studies by the Corps of Engineers, United States Army, in 1935, based on discharge measurements at Montpelier, Vt., show that floods exceeding concurrent channel capacity in the lower section occur, on the average, once every 2 years; floods nearly twice as great as channel capacity, once every 20 years; floods three times channel capacity, once in 50 years; and floods over six times channel capacity, once every 100 years.

The channel capacity of the Winooski between Richmond and North Williston, Vt., was determined by the Corps of Engineers to be about 18,000 to 19,000 cubic feet per second. Thus, when discharge exceeds 18,000 cubic feet per second, banks overflow, although actually overflow may occur locally at lesser discharges on certain stretches where banks are low. The United States Geological Survey has maintained an automatic recording stream-gage station near Essex Junction, Vt., since September 1928. A summary of peak discharges for each year for the 17-year period, October 1928 through September 1945, as determined from these reports, is given in table 1. The maximum mean daily flow per month for the same period is shown in figure 26.

Discharges measured at Essex Junction would be only slightly larger than those occurring between North Williston and Richmond, since the drainage basin between Essex Junction and Richmond is narrow and the contributing drainage area above Essex Junction is not much greater than that above Richmond. An analysis of annual peak discharge for the 17-year period of record at Essex Junction indicates that in the section between North Williston and Richmond, bank-full or greater discharge occurs, on the average, about once a year; discharge equal to or greater than twice channel capacity occurs once in 7 years; and discharges equal to or greater than three times channel capacity, once every 30 years.

Subsequent to the installation of bank-protective measures, peak flow has equaled or exceeded channel capacity in 7 out of 10 years

[3] For detailed information on general characteristics, including hydrology, of the Winooski River Basin see: House Document No. 785, 71st Cong., 3d Sess., 1931; House Document No. 656, 76th Cong., 3d Sess., 1940; House Document No. 629, 78th Cong., 2d Sess., 1944.

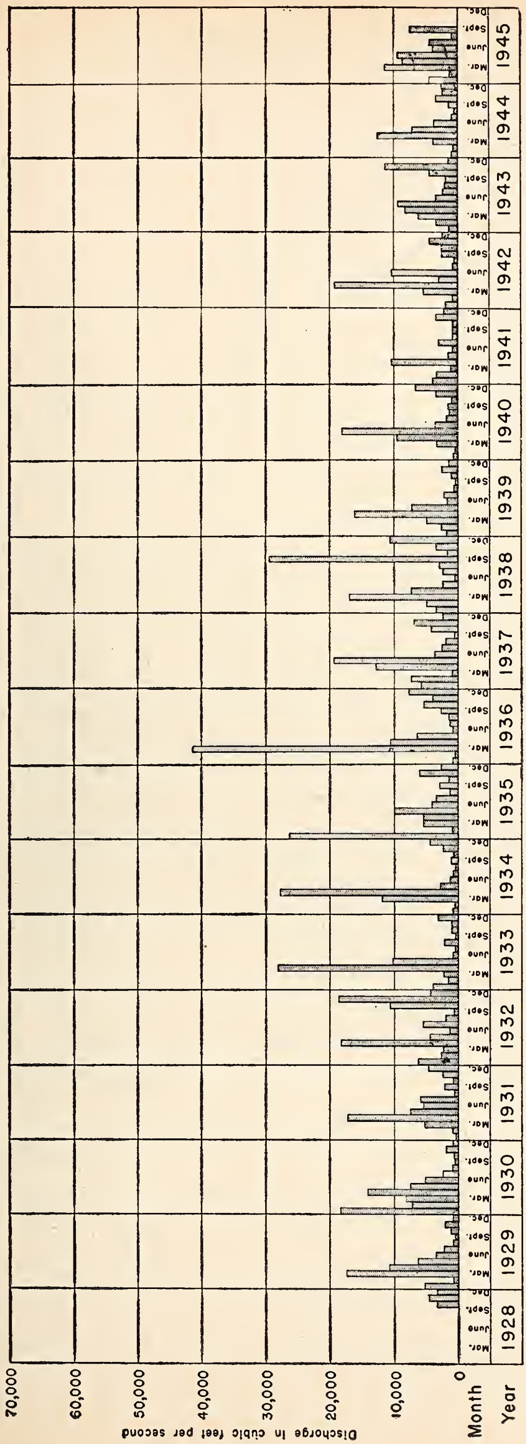

FIGURE 26.—Maximum mean daily discharge per month of the Winooski River at Essex Junction, Vt.

TABLE 1.—*Summary of peak discharge per water year on the Winooski River at Essex Junction, Vt.*[1]

Water year	Day	Peak discharge	Water year	Day	Peak discharge
		Cubic feet per second			*Cubic feet per second*
1929	Mar. 17	20, 400	1938	Sept. 22	34, 300
1930	Jan. 9	23, 500	1939	Apr. 20	18, 200
1931	Apr. 11	22, 600	1940	May 3	22, 800
1932	Apr. 13	23, 600	1941	Apr. 14	11, 900
1933	Apr. 19	34, 600	1942	Apr. 16	22, 400
1934	Apr. 13	31, 600	1943	May 12	12, 900
1935	Jan. 10	30, 900	1944	Nov. 9	18, 000
1936	Mar. 19	45, 300	1945	May 19	12, 900
1937	May 16	26, 400			

[1] The data indicate that overflow occurs in this section of the stream almost annually.

of record. Two floods, those of March 18, 1936, and September 22, 1938, were the fourth and fifth largest of record in the Winooski River Basin, having been exceeded only by the floods of 1830, 1869, and 1927. Peak discharge of the 1927 flood at Essex Junction was estimated to be 113,000 cubic feet per second. Peak discharges of the 1830 and 1869 floods were estimated by the Corps of Engineers to be 80 percent and 65 percent, respectively, of the 1927 flood.

Peak discharge of the March 1936 flood, without detention in upstream flood-control dams, would have been approximately 51,100 cubic feet per second at Essex Junction, according to estimates by the Corps of Engineers. Actually, with detention, it amounted to 45,300 cubic feet per second. The unregulated flow for the September 1938 flood would have been 42,500 cubic feet per second, but this was reduced to 34,300 cubic feet per second by the flood-control reservoirs. The reduction in peak flow in 1936 occurred with only two flood-control reservoirs in operation while that in 1938 occurred with three in operation.

Detailed studies have not been made on the Winooski to determine the relationship of stream discharge and stage to rate of bank erosion. The severe erosion of banks caused by the heavy flood of 1927, however, indicates that, for conditions on this river, the greater the discharge, the greater is its erosion potential.

The bank-protective works, in the main, have withstood the erosive force of a flood with peak discharge up to 34,300 cubic feet per second. Such a flood occurred on September 22, 1938. With proper maintenance, these works may be expected to withstand a flood which has a recurrence interval of once in about 20 years. Further observation and test is needed to determine their ability to withstand greater floods. Since some of the protective measures have been weakened and damaged by ice action, toe cutting, and other causes, the damaged banks may start eroding again, even during small floods such as might be expected to occur annually, unless early repairs are made.

The severity of chute erosion depends partly upon the depth and discharge of water when the flow leaves the channel and overtops the banks. Chute barricades and other measures designed to reduce the velocity of flow through chutes have not been subjected to floods with erosive forces equal to that of the 1927 flood when most of the chutes were formed. They have, however, withstood a flood having a frequency of about once in 20 years. Ice jams may have raised water stages locally, causing an increase in depth and velocity of flow through some of the chutes, but facilities were not available for testing the performance of protective measures under these extreme conditions.

Flood-Control Dams on the Winooski Watershed

Three flood-control dams have been constructed in the Winooski Basin: East Barre Dam on the Jail Branch and Wrightsville Dam on the North Branch, both completed in 1935; and Waterbury Dam on the Little River, completed in 1937. East Barre Dam has a flood-storage capacity to spillway crest of 12,100 acre-feet and controls the runoff from a discharge area of 39 square miles. Wrightsville Dam has a storage capacity to spillway crest of 20,500 acre-feet and controls the runoff from 70 square miles. Waterbury Dam has a flood-control storage capacity of 28,500 acre-feet and a conservation-storage capacity of 36,000 acre-feet. It controls the runoff from a drainage area of 109 square miles.

Wrightsville and East Barre Dams are provided with ungated concrete conduits near stream-bed level that are designed to release a flow equivalent to bank-full stage downstream from each dam while the reservoirs are filling with floodwater. The flow from Waterbury Dam is controlled by two 48-inch needle valves for flow regulation. Flood-flow release is controlled by two sector gates recessed in the spillway crest.

A comparison of hydrographs of floods on the Winooski before and after constructiton of the reservoirs shows that, in general, the average stage at peak flow was about 1.5 feet lower after construction of dams than before. There was no apparent effect on stage on the day following the peak flow, but on the second day following peak flow the regulated stage was, on the average, 0.9 foot higher than the nonregulated flow. On the third day following peak discharge, the stage of regulated flow was, on an average, 0.5 foot higher, but thereafter there was no apparent difference in stage between spring floods prior to construction of the flood-control dams and those after the dams were put in operation.

A study of all floods on the Winooski, including spring floods and those occurring at other times of the year, showed that regulated flows for several days following the peak discharge were, on the average, a foot or so higher after construction of the flood-control reservoirs than before, but 3 or 4 days after the peak discharge no apparent change in stage was evident.

Insofar as flood discharges are concerned, therefore, it may be concluded that peak-discharge stages declined, on the average, following construction of the flood-control dams, but that for 2 or 3 days following peak-discharge stage, the stage is somewhat higher, amounting to 0.5 to 1.0 foot, depending on the nature and intensity of discharge.

The original plan for flood control in the Winooski Basin, as proposed by the Corps of Engineers, called for the construction of seven reservoirs designed to control the runoff from an aggregate drainage area of 615 square miles, or 57 percent of the total drainage area above the Essex Junction gaging station. Actually, only three reservoirs were built. These control the runoff of 218 square miles, or 20 percent of the drainage area above Essex Junction.

As originally planned, the flood-control dams would have reduced peak-flood discharges to about one-third their natural volume. This would be sufficient to reduce flood damages to residential and manufacturing towns in the upper part of the watershed. Discharges, however, still would be large enough to cause overflow of bottom lands in the lower sections at times of maximum floods. The flood-control reservoirs have reduced peaks at Essex Junction only slightly. They may have prolonged runoff briefly from excessive floods, but this is not readily apparent from an analysis of the discharge records.